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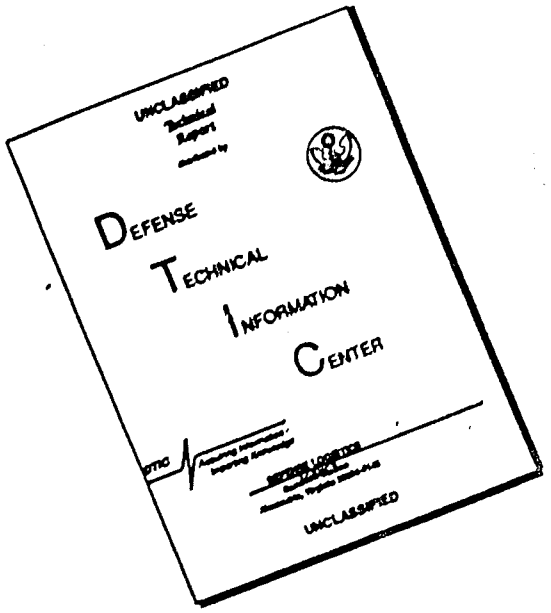

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HUMAN TOLERANCE
TO ACCELERATIONS:
A PRACTICAL GUIDE
FOR THE ENGINEER

International Airport, Los Angeles 45, California
LOS ANGELES DIVISION

File No. _____ Report No. NA-57-425

NORTH AMERICAN AVIATION, INC.

INTERNATIONAL AIRPORT
LOS ANGELES 45, CALIFORNIA

ENGINEERING DEPARTMENT

HUMAN TOLERANCE TO ACCELERATIONS: A PRACTICAL TOOL FOR THE ENGINEER

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No. of Pages 30

REVISIONS

Date 6 May 1957

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13 JUNE 1957	S. O.	24, 26	CORRECTION OF EQUATIONS AND SPELLING ERR.

HUMAN TOLERANCE TO ACCELERATIONS:

A PRACTICAL TOOL FOR THE ENGINEER

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NORTH AMERICAN AVIATION, INC.
LOS ANGELES, CALIFORNIA

PRESENTED ON MAY 6, 1957, AT THE
28th ANNUAL MEETING OF THE
AERO MEDICAL ASSOCIATION,
DENVER.

HUMAN TOLERANCE TO ACCELERATIONS:
A PRACTICAL TOOL FOR THE ENGINEER

Several elements must be considered in predicting the effect of acceleration upon the human body: the magnitude of the acceleration, its time duration, the associated rate of onset, the direction of the accelerating force, the density and location of application to the body surfaces, and cyclic diminutions and reversals. The element which provides the greatest opportunity to the engineering designer is direction of application of the force producing the acceleration, optimization of which yields important physiological dividends.

A study of reports on laboratory experiments, survived falls, and an escape from an airplane at supersonic speed has been conducted and data accumulated to provide a practical tool for the engineer in evaluating human tolerance to accelerations.

Magnitudes from 1.5 G to 200 G, time durations from 0.001 to 1000 seconds, rates of onset from 0.10 to 5000 G/second and various directions of resultant acceleration vectors are compared with permanent injury threshold, limits of voluntary tolerance, and limits of useful consciousness as criteria.

DEFINITIONS

PERMANENT INJURY THRESHOLD is here defined as the threshold of trauma irreversible by surgery or therapy.[13] The specific physiological limits establishing the permanent injury threshold vary from hemorrhage to shock, anoxia, and mechanical injury.

LIMIT OF VOLUNTARY TOLERANCE is defined as the area of human capacity within which applied accelerations can be expected to produce no worse than short periods of extreme discomfort or unconsciousness. The specific limits include petechiae, pain, difficulty of respiration, blackout-to-unconsciousness, and threshold of shock and mechanical injury.

LIMIT OF USEFUL CONSCIOUSNESS is the boundary of awareness sufficient for proper response to stimuli which normally generate familiar, well-indoctrinated reactions. Physiological symptoms at the defined limits are petechiae, pain, difficulty of respiration, and blackout.

The four acceleration parameters treated are:

(1) Magnitude - The force in multiples of gravity or G units.

(2) Duration - The time, in seconds, at the G plateau.

(3) Rate of Onset - The rate of change of acceleration in G/second units, as measured on the significant slope of the acceleration versus time curve.

(4) Direction - Angles, in degrees, varying from zero degrees, when the external accelerating force acts transversely from chest-to-back (H+), to ±180 degrees when the force is produced from back-to-chest (H-). At +90 degrees, force direction is seat-to-head (V+); at -90 degrees, force is head-to-seat (V-), as shown diagrammatically on graphs 9 through 18.

All these parameters are related to direct experience by the subject; they are not values measured on the test vehicle, seat, or other external bodies.

The restraint harness is assumed to be at least equivalent to that recommended by Stapp in 1951: shoulder harness of 1.75-inch width, No. 13 nylon webbing, with lap belt and inverted "V" leg strap of 3-inch width nylon of adequate strength.[26] Head and limb retention aids are presupposed for acceleration levels exceeding 30 G.

A dearth of experimental data precludes other than a theoretical analysis of cyclic diminutions and reversals - consequently, no attempt is made here to determine effects in that area.

METHOD

Interpretation and methodology employed are similar to those of an earlier, related study.[14]

Graphs 1 through 8 relate directly the parameters of magnitude, duration, and direction in a manner originated by Lombard.[18] The limits were derived by evaluating the plotted data, which include both human and animal subjects. All lines, except one, are well substantiated by available information. In the one case, the H- permanent injury threshold was extrapolated from the corresponding H+ threshold.

Elliptic resolution of forces[13] was adopted to predict values undefined by graphs 1 through 8, which set the limits at only zero, +90, -90 and ± 180 degrees.

For the permanent injury threshold, a purely elliptic resolution was applied for all durations, as shown in graphs 9 through 11.

Voluntary tolerance limits were derived by the unmodified elliptic method for durations less than 0.20 second, graphs 12 and 13. For these short durations, body fluid movements are assumed to be negligible.[29] However, for longer time periods, fluid movement becomes evident and the end points become governed by the heart-to-retina line, inclined approximately 28 degrees forward from the axis of the vertebral column.[6, 12, 16] Consequent shifts in the ellipse major and minor axes are indicated, as shown in graph 14. However, the region from +90 to +180 degrees has been explored by extensive tests and found to be divorced from the conventional elliptic resolution.[4, 12, 17, 20, 22, 30]

The limits of useful consciousness were determined by the modified elliptic method, graph 15. Again, the region from +90 to +180 degrees differs in the same fashion as for voluntary tolerance.

Graph 16 studies rates of onset and their effect on the limits of voluntary tolerance. From the plotted points, representing data on human subjects only, significant limits for $H\pm$, V+ and V- jolts have been derived. It should be noted that placement of the limit traces is such as to produce conservative values for jolt in the equation of graph 18.

The series of curves indicating the permanent injury threshold (graph 17) show characteristic maxima occurring at zero and ± 180 degrees, and minima at ± 90 degrees.

(1) In the vicinity of zero and ± 180 degrees, retinal hemorrhage occurs at low G, long duration, and at moderate rates of onset; shock and injury occur at higher G, shorter duration, and higher rates of

onset.[2, 5, 18, 26, 27, 28, 29, ...]

(2) Near ± 90 degrees, hemorrhage occurs at low G, long duration, and at moderate rates of onset.[2, 10, 15, 19] Anoxia may occur at the long duration exposures due to stress on the lungs.[11] Spinal injury is sustained at high G, short duration, and high rates of onset.[19, 28]

Stapp has exposed chimpanzees to acceleration peaks of 100 G or more at jolts approximating 20,000 G/second. In selected experiments, severe shock was experienced in the V- direction of application, moderate shock in the H+ direction, and no injury at H-.[28] These results suggest that jolt ceilings up to 10,000 G/second would not be unconservative in relation to the human permanent injury thresholds of graph 17.

The series of curves delineating the limits of voluntary tolerance (graph 18) show the usual maxima at zero and ± 180 degrees, and minima at ± 90 degrees for short durations (less than 0. 2 second). With increased durations, a shift of maxima occurs from zero to approximately +28 degrees and from +90 to +118 degrees.[12, 16] A slight shift also is shown in the vicinity of -90 degrees.[16]

(1) Zero Degrees - At low G range for long duration and low rates of onset, severe petechiae in the extended arms, or in the eyes, are the initial symptoms defining voluntary tolerance boundaries.[1,7,8] With increase in acceleration magnitude, decrease in duration and increase in the rates of onset, the limits are governed by severe pain, due to distended organs, and extreme difficulty of

respiration.[1, 7, 8, 19, 29] At high G, short duration, and high rate of onset, the threshold of shock is approached.[15, 26, 28, 29]

(2) +90 Degrees - Blackout-to-unconsciousness and severe petechiae determine the limits as the condition changes from low G, long duration, and low rates of onset to higher G, shorter duration, and higher rates of onset.[3, 4, 6, 33] At high G, short durations, and high rates of onset, the threshold to injury is approached.[19, 32] Injury is usually fracture of vertebrae.[19]

(3) ±180 Degrees - The approach from +90 to +180 degrees shows a lag in the increase of G tolerance for conditions of low G, long duration, and low rate of onset. However, a sharp increase occurs from +167 to +180 degrees.[12] The physiological symptoms vary from severe pain and petechiae to extreme difficulty in breathing.[1,7,8] The threshold of shock establishes the limit for high G, short duration, and high rates of onset.[26, 27, 28]

(4) -90 Degrees - Severe petechiae and pain, at low G, long duration, and low rates of onset, change to threshold of injury at high G, short duration, and high rates of onset, as the physiological limits of negative acceleration.[10, 15, 16, 28, 33]

An empirical equation and curve, derived from the rate of onset study (graph 16) permit calculation of the maximum allowable jolts related to a given maximum acceleration.

The series of curves indicating the limits of useful consciousness (graph 19) again are produced by elliptic resolution of forces. Due to the critical

heart-to-eye axis, maxima and minima are displaced from zero and ±90 degrees.

(1) Zero Degrees - Mild petechiae are the first physiological symptoms determining useful consciousness boundaries under conditions of low G, long duration, and low rates of onset.[1, 23] With increased acceleration, shorter duration, and low rates of onset, pain becomes predominant.[1, 23] High G magnitude, with corresponding short duration and moderate rates of onset, reaches the point where respiration becomes difficult.[1, 15, 16, 22]

(2) +90 Degrees - Blackout and mild petechiae are the limiting symptoms.[4, 6, 9, 12, 17, 20, 21, 30, 31] The minimum points are reached at approximately +118 degrees, when the direction of the accelerating force acts coincident with the heart-to-retina line.[12, 16]

(3) ±180 Degrees - A lag in the increase in acceleration tolerance prevails up to +167 degrees; a sharp increase is noted thereafter.[12] The end point of mild petechiae, at low G, long duration, and low rate of onset, changes to pain and difficulty of respiration with increase in G, shorter duration, and moderate rates of onset.[1,12,23,30]

(4) -90 Degrees - Mild pain and petechiae are the limiting symptoms.[10,13,24, 25]

The rate of onset for these series of curves is assumed to be between one G/second and 100 G/second. Gradual rates of onset of less than one G/second have been found to increase tolerance by approximately 2 G.[9, 21] The reason for the increase is due to the cardiovascular reflex activity having ample time to develop fully before the critical plateau of blackout is

reached.[9, 21] The time to develop has been found to be approximately 6 to 7 seconds.[9, 21]

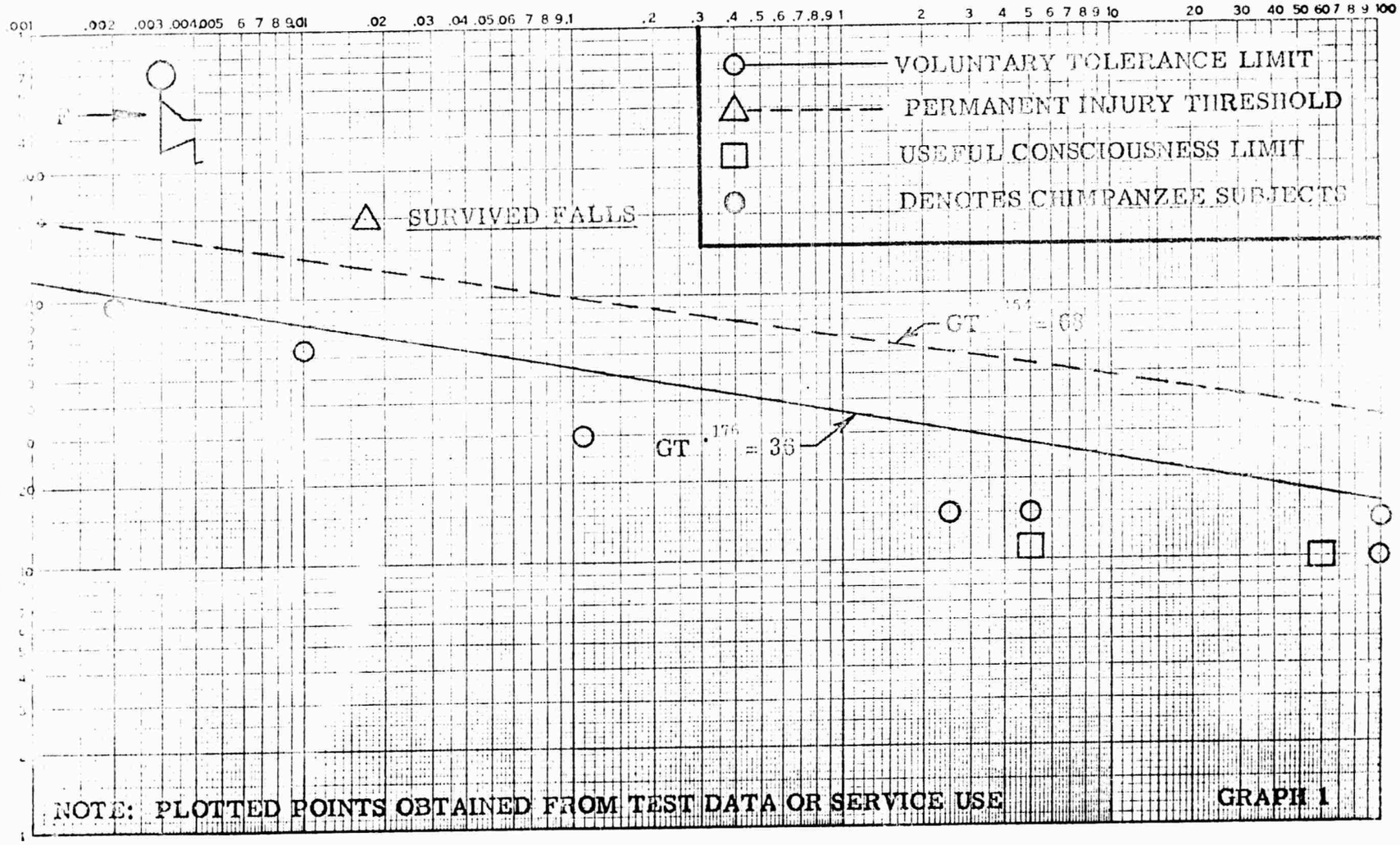
CONCLUSIONS

A scarcity of information on human accelerative effects necessitates extrapolation from isolated experimental results. Fortunately, this extrapolation may be founded on logical patterns formed by existing datum points.

KEUFFEL & ESSER CO., N. Y. NO. 359-1590
Logarithmic, 5 × 3 Cycles
MADE IN U.S.A.

II - INJURY

TIME IN SECONDS

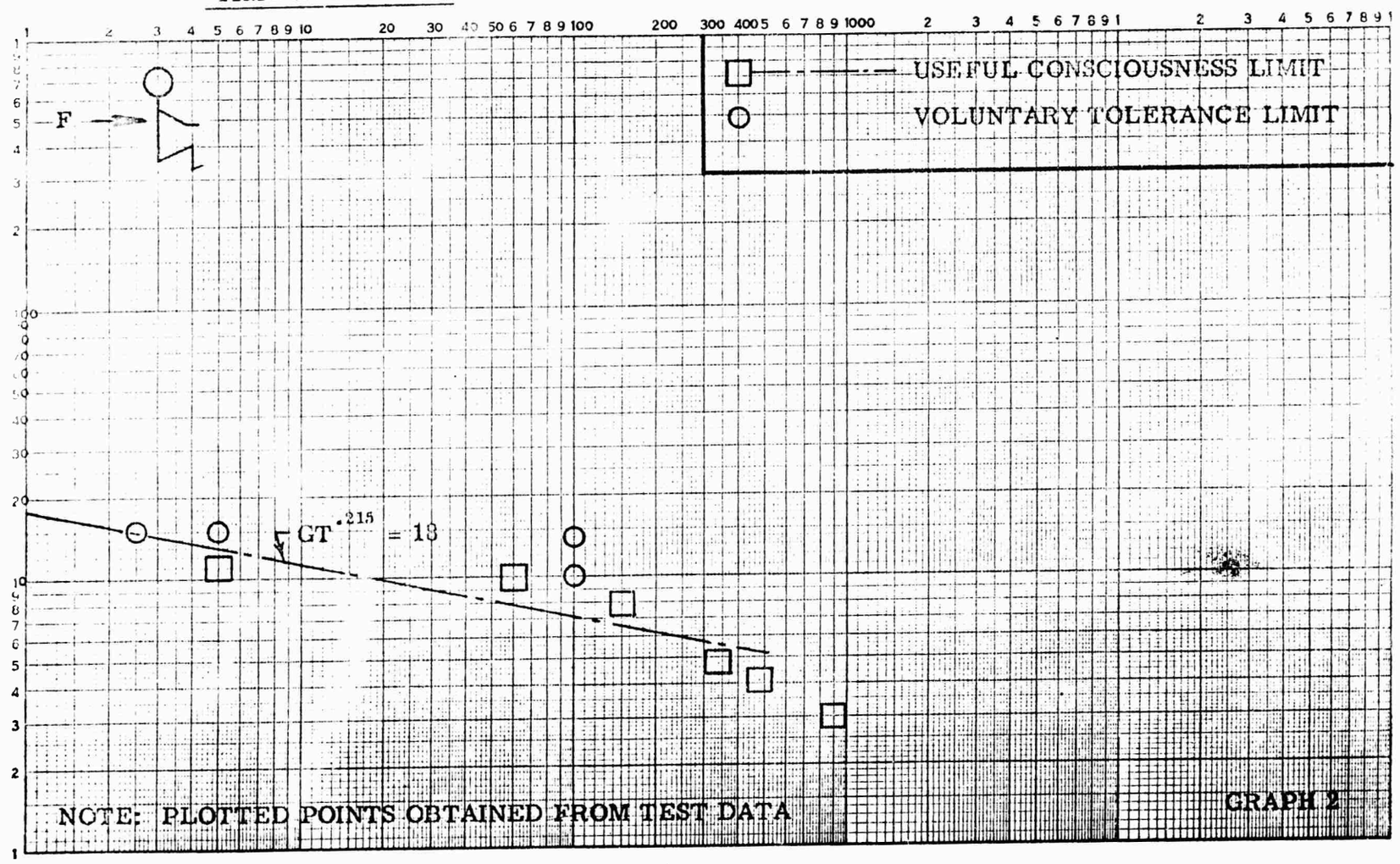


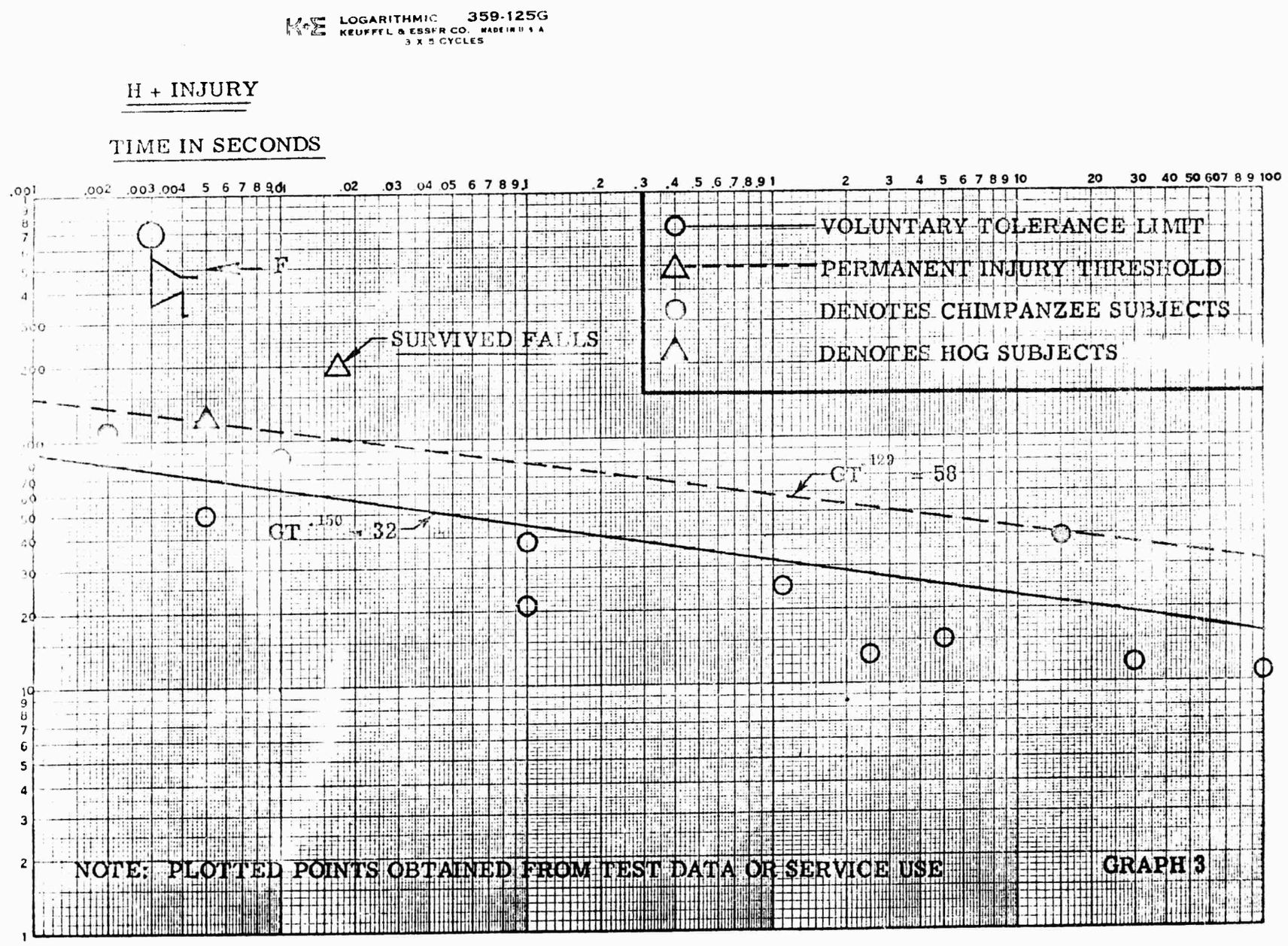
NOTE: PLOTTED POINTS OBTAINED FROM TEST DATA OR SERVICE USE

GRAPH 1

KEUFFEL & ESSER CO., N. Y. NO. 359-1850
Logarithmic, 5 X 3 Cycles.
MADE IN U. S. A.

H- USEFUL CONSCIOUSNESS LIMIT

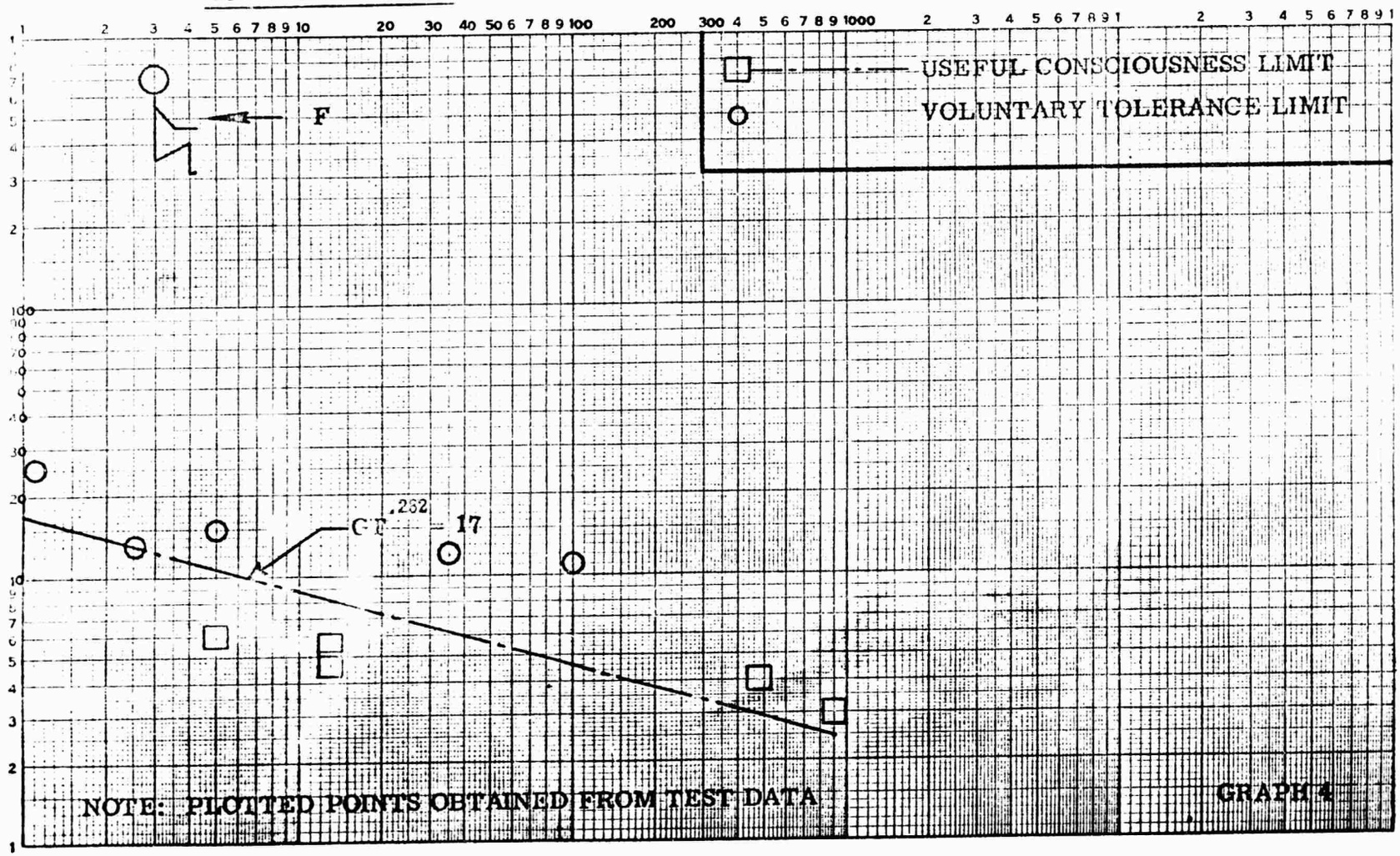



K&E LOGARITHMIC 359-125G
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 X 5 CYCLES
H + INJURY
TIME IN SECONDS
ACCELERATION
.001 .002 .003 .004 5 6 7 8 9 .01 .02 .03 .04 .05 6 7 8 9 .1 .2 .3 .4 .5 .6 7 8 9 1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 7 8 9 100
F
SURVIVED FALLS
VOLUNTARY TOLERANCE LIMIT
PERMANENT INJURY THRESHOLD
DENOTES CHIMPANZEE SUBJECTS
DENOTES HOG SUBJECTS
GT 129 = 58
GT .150 = 32
NOTE: PLOTTED POINTS OBTAINED FROM TEST DATA OR SERVICE USE
GRAPH 3

KEUFFEL & ESSER CO., N. Y. NO. 359-1256
Logarithmic, 6 X 3 Cycles
MADE IN U. S. A.

+Gx USEFUL CONSCIOUSNESS LIMIT

TIME IN SECONDS



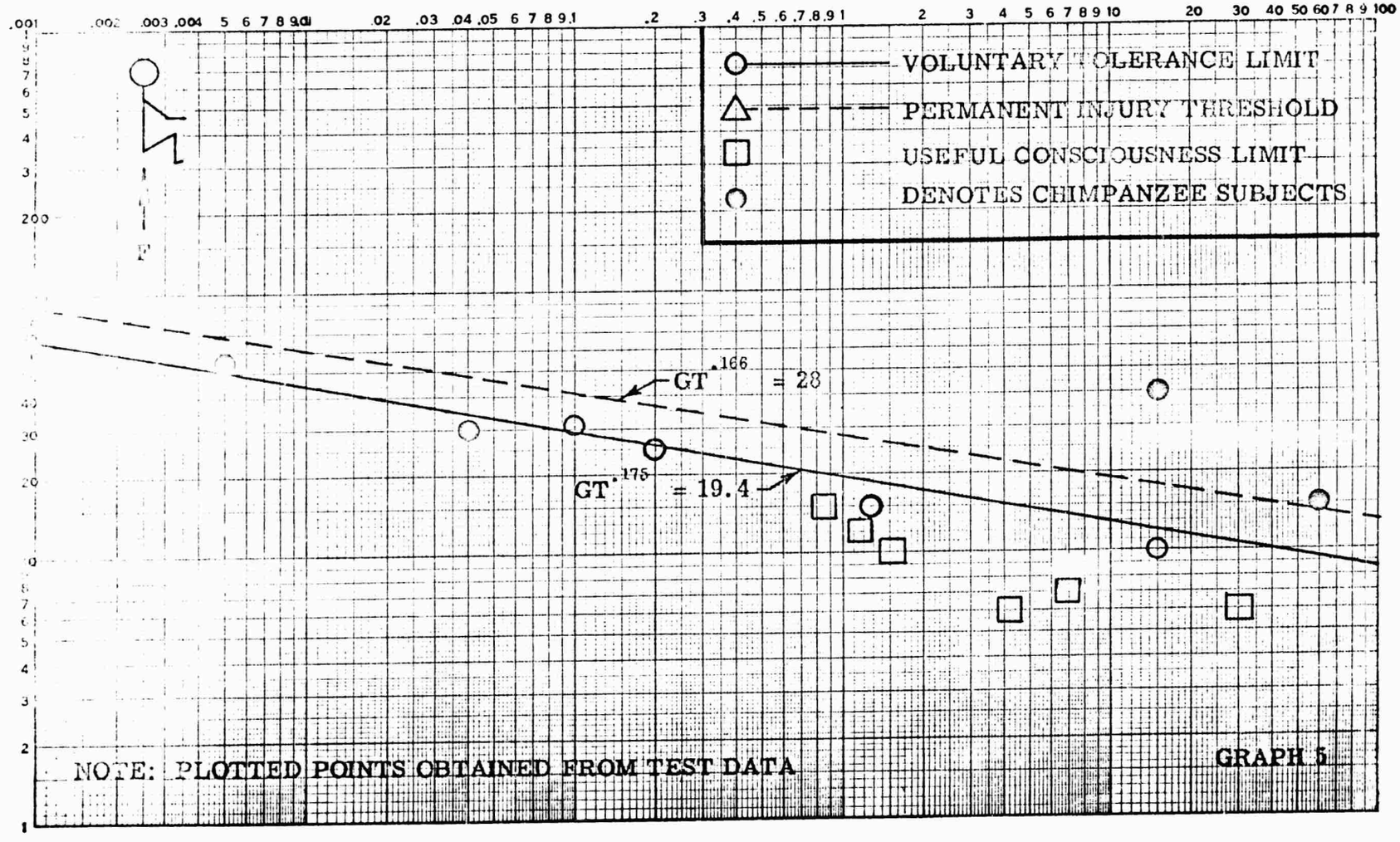
NOTE: PLOTTED POINTS OBTAINED FROM TEST DATA

GRAPH 4

KEUFFEL & ESSER CO., N. Y. NO. 359-1295
Logarithmic, 5 X 5 Cycles.
MADE IN U. S. A.

V + INJURY

TIME IN SECONDS



ACCELERATION ... "G" UNIT

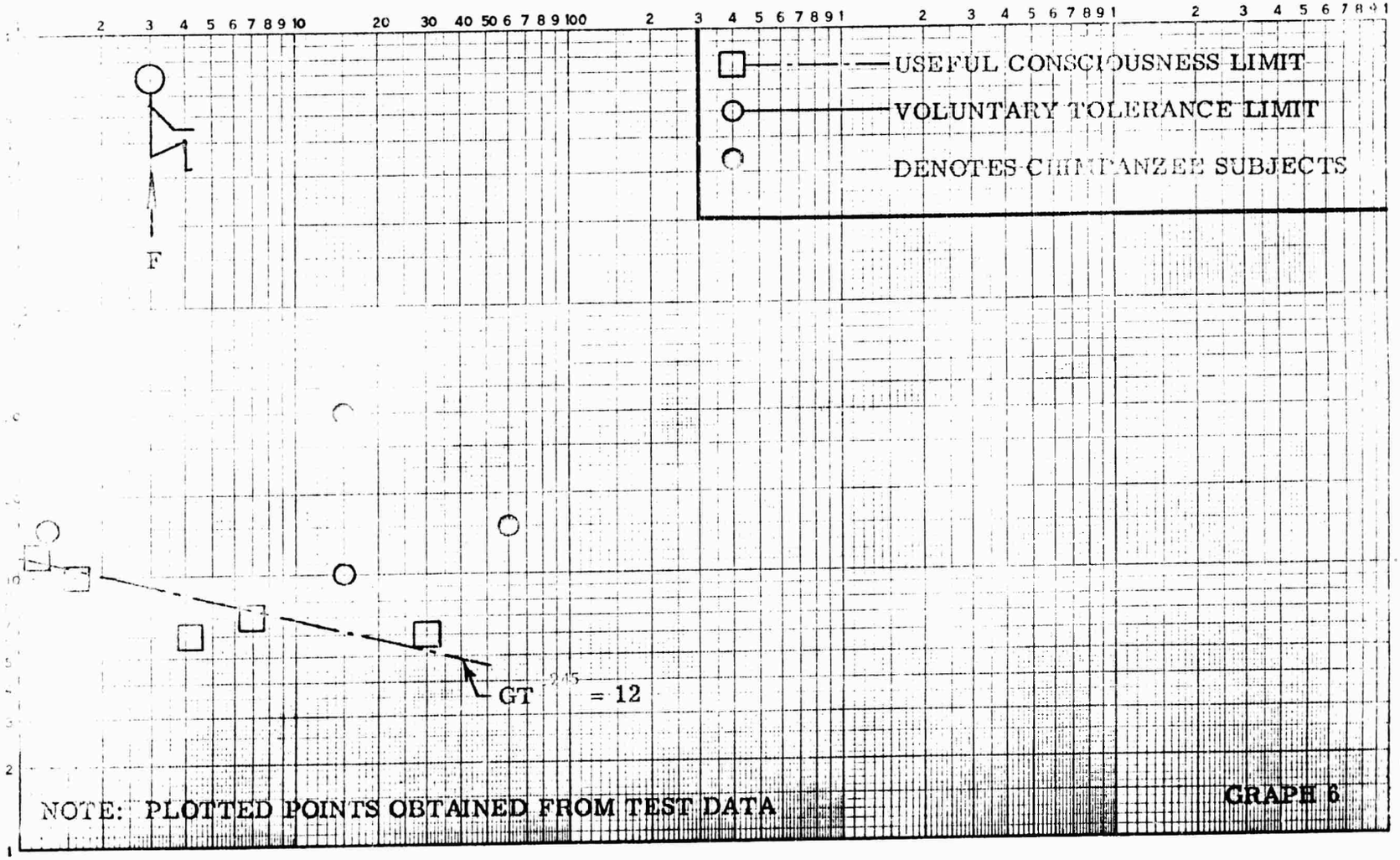
NOTE: PLOTTED POINTS OBTAINED FROM TEST DATA

GRAPH 5

KEUFFEL & ESSER CO., N. Y. NO. 359-1850
Logarithmic, 5 X 5 Cycles.
MADE IN U.S.A.

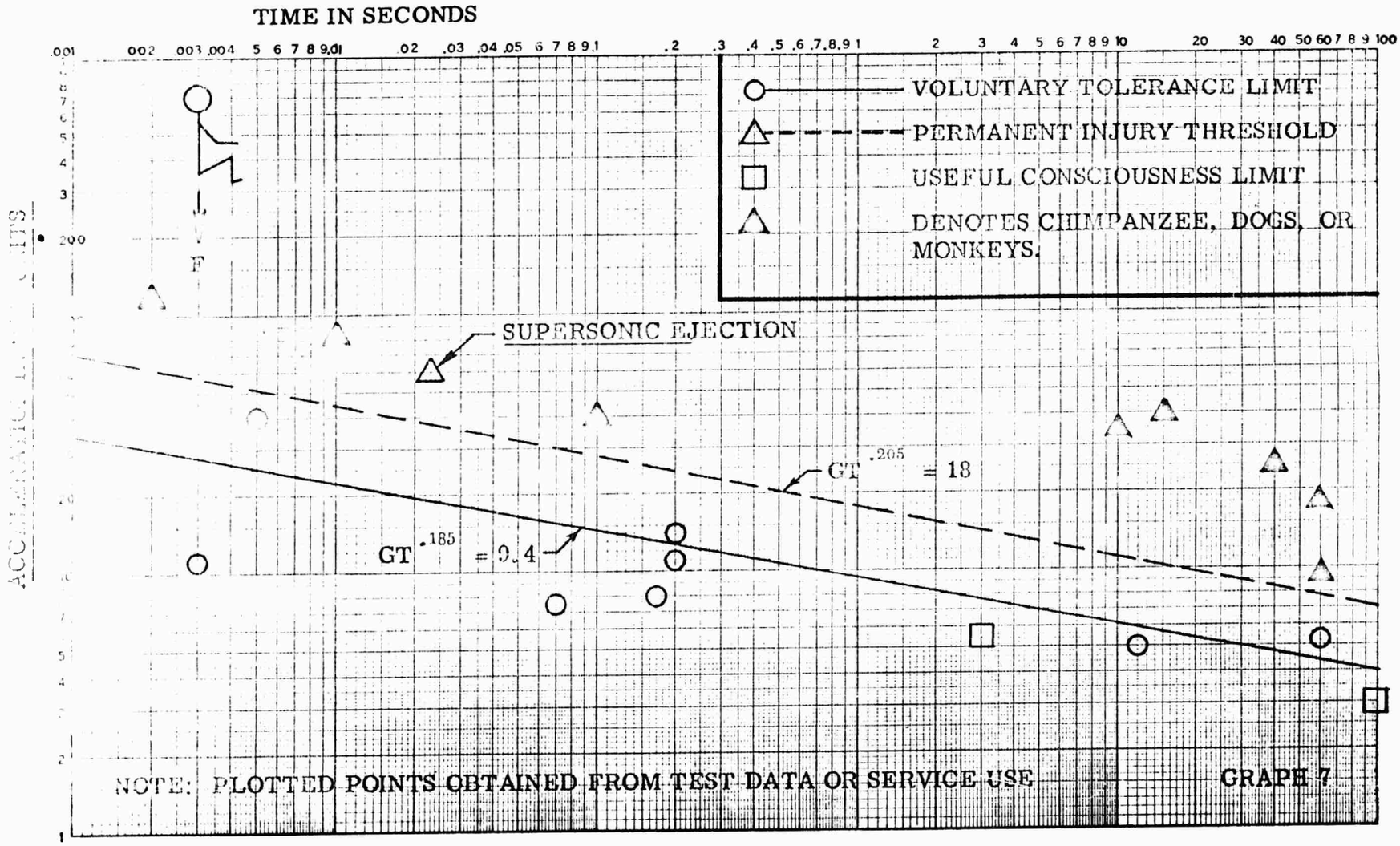
V+ USEFUL CONSCIOUSNESS LIMIT

TIME IN SECONDS



GRAPH 6

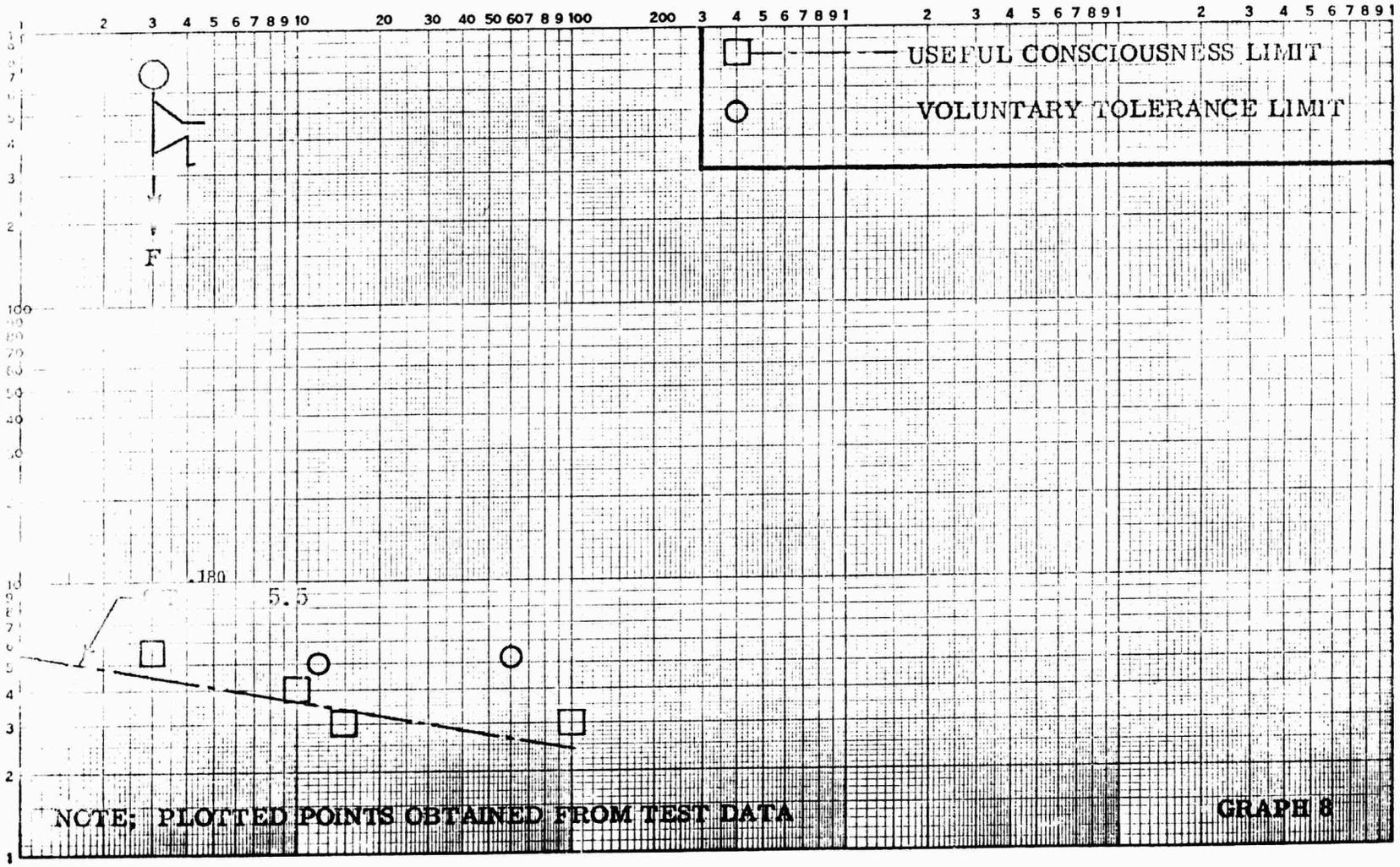
V- INJURY



K+E LOGARITHMIC 359-125G
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 X 5 CYCLES

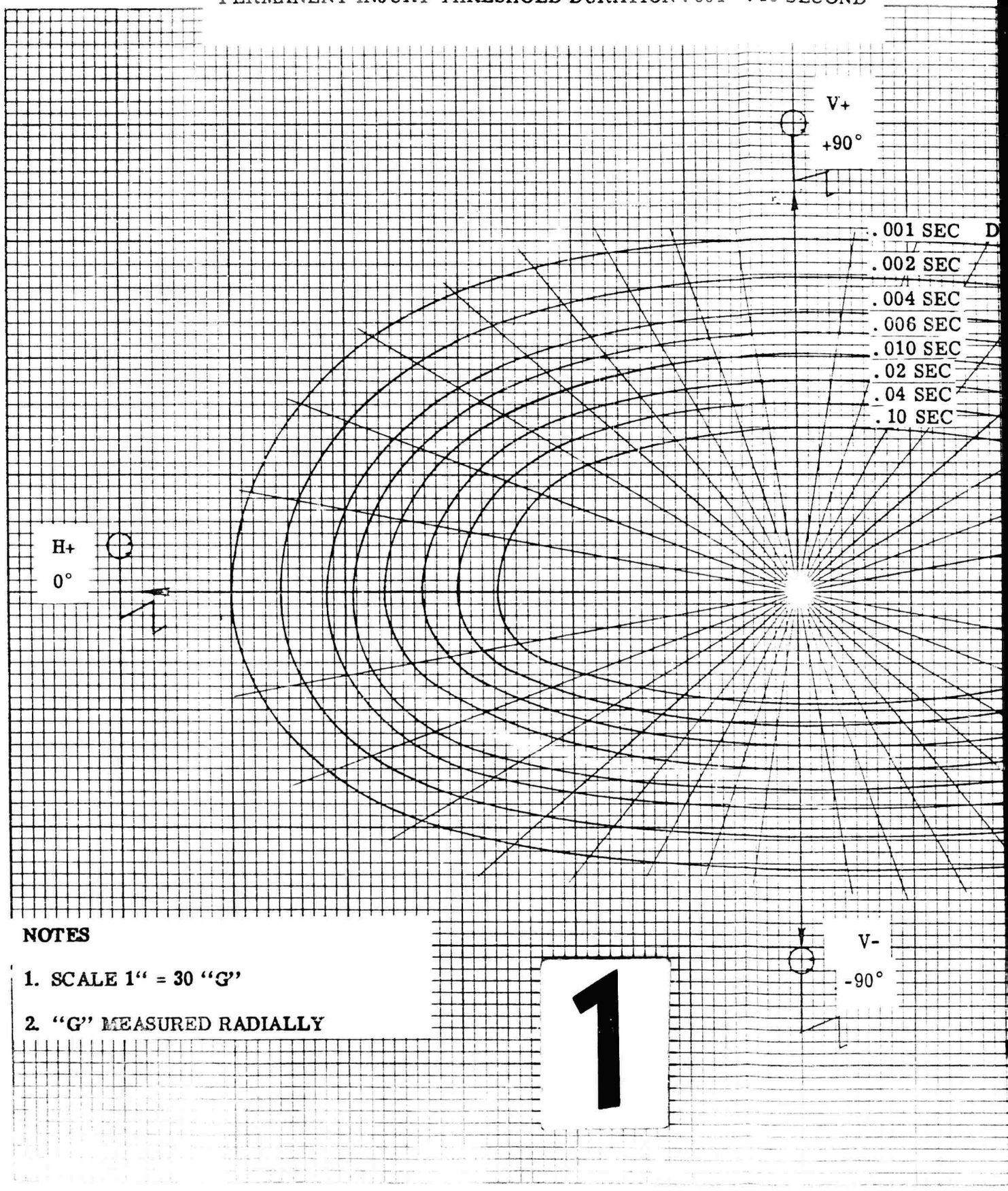
V- USEFUL CONSCIOUSNESS LIMIT

TIME IN SECONDS



ACCELERATION IN "G" UNITS

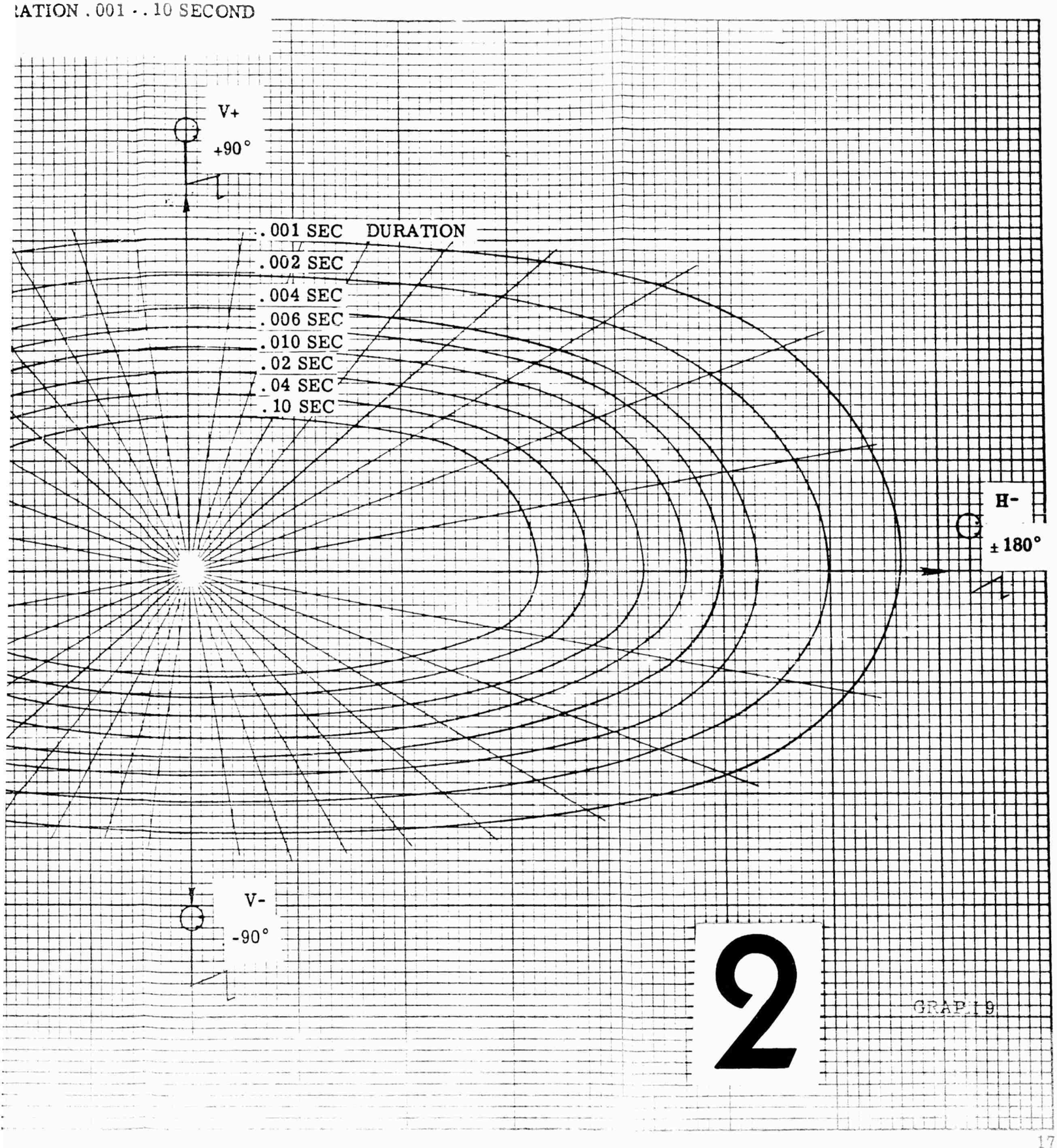
PERMANENT INJURY THRESHOLD DURATION . 001 - . 10 SECOND



NOTES

1. SCALE 1" = 30 "G"
2. "G" MEASURED RADIALLY

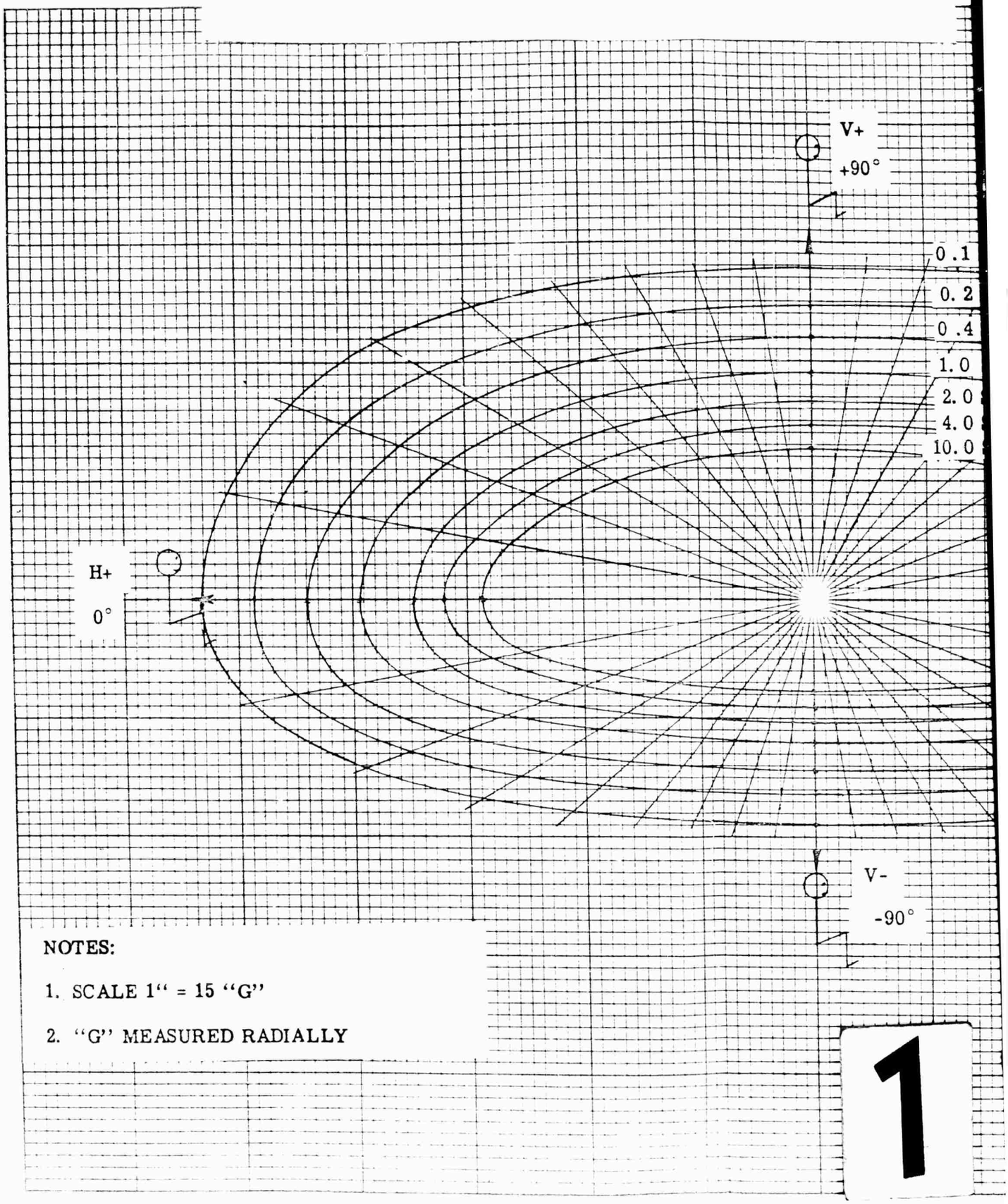
1


V+
+90°
.001 SEC DURATION
.002 SEC
.004 SEC
.006 SEC
.010 SEC
.02 SEC
.04 SEC
.10 SEC
H-
± 180°
V-
-90°

2

GRAPH

PERMANENT INJURY THRESHOLD - DURATION 0.1 - 10.0 SECONDS



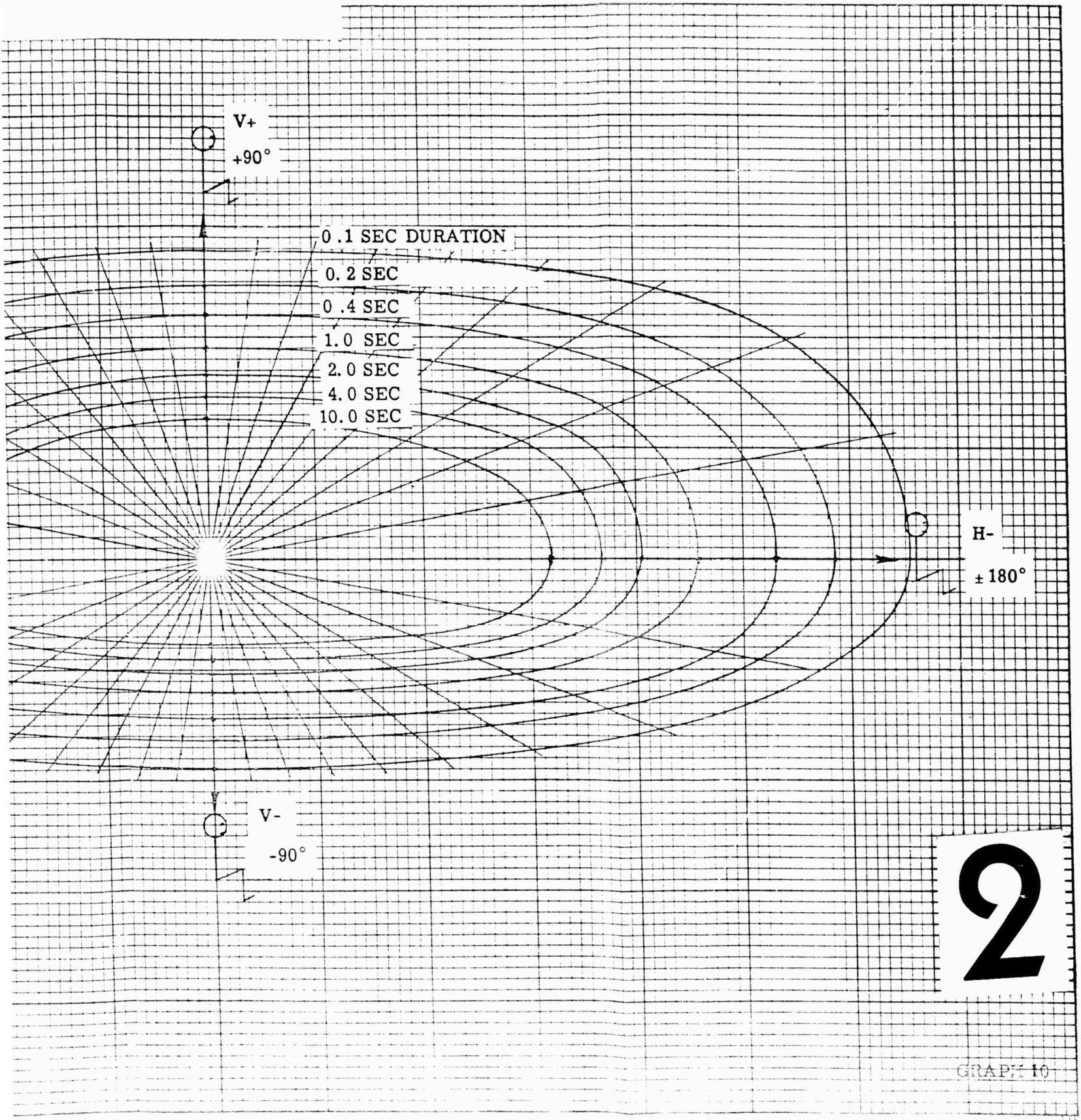
NOTES:

1. SCALE 1" = 15 "G"

2. "G" MEASURED RADIALLY

1

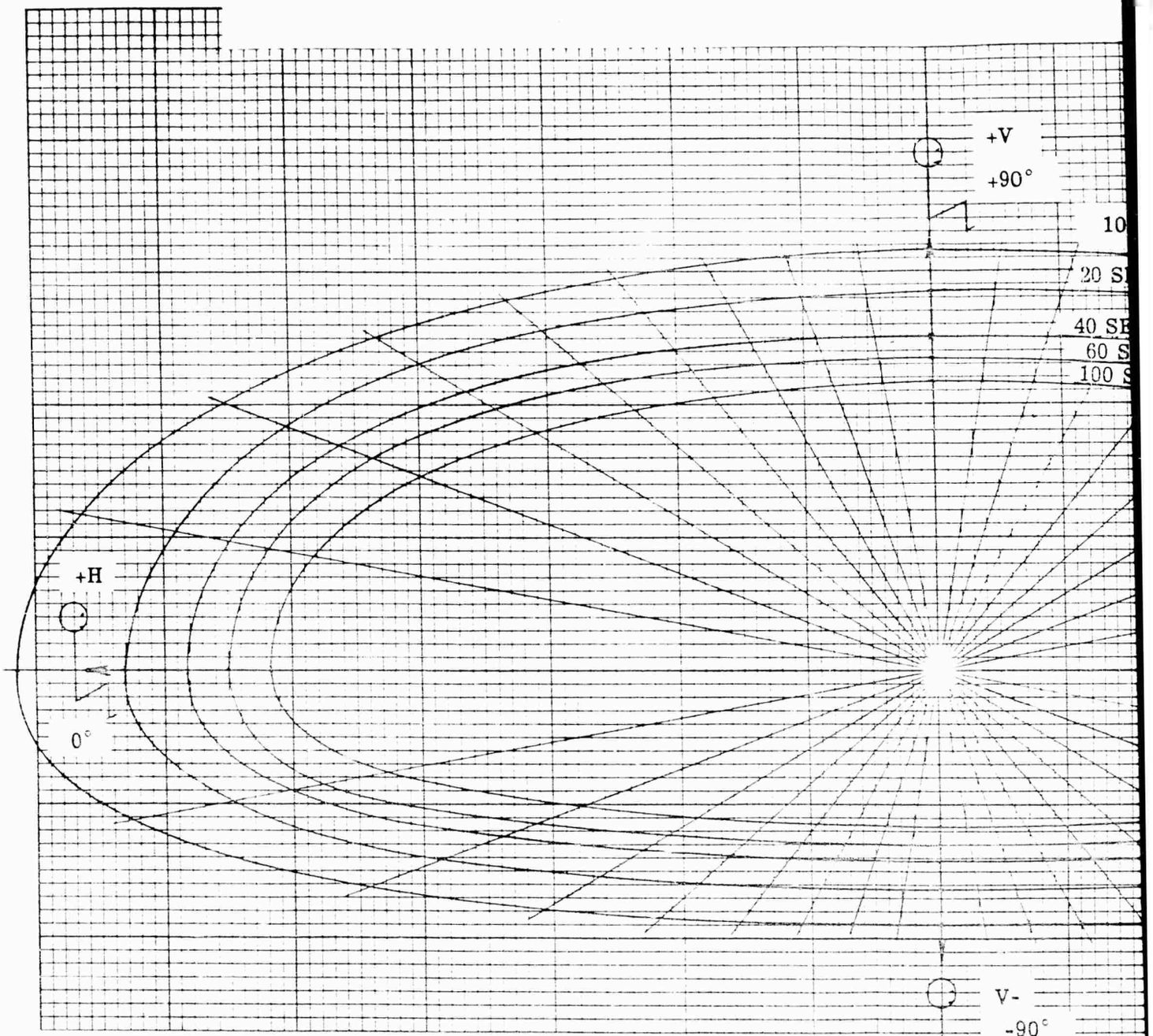
DURATION 0.1 - 10.0 SECONDS



2

GRAPH 10

PERMANENT INJURY THRESHOLD - DURATI



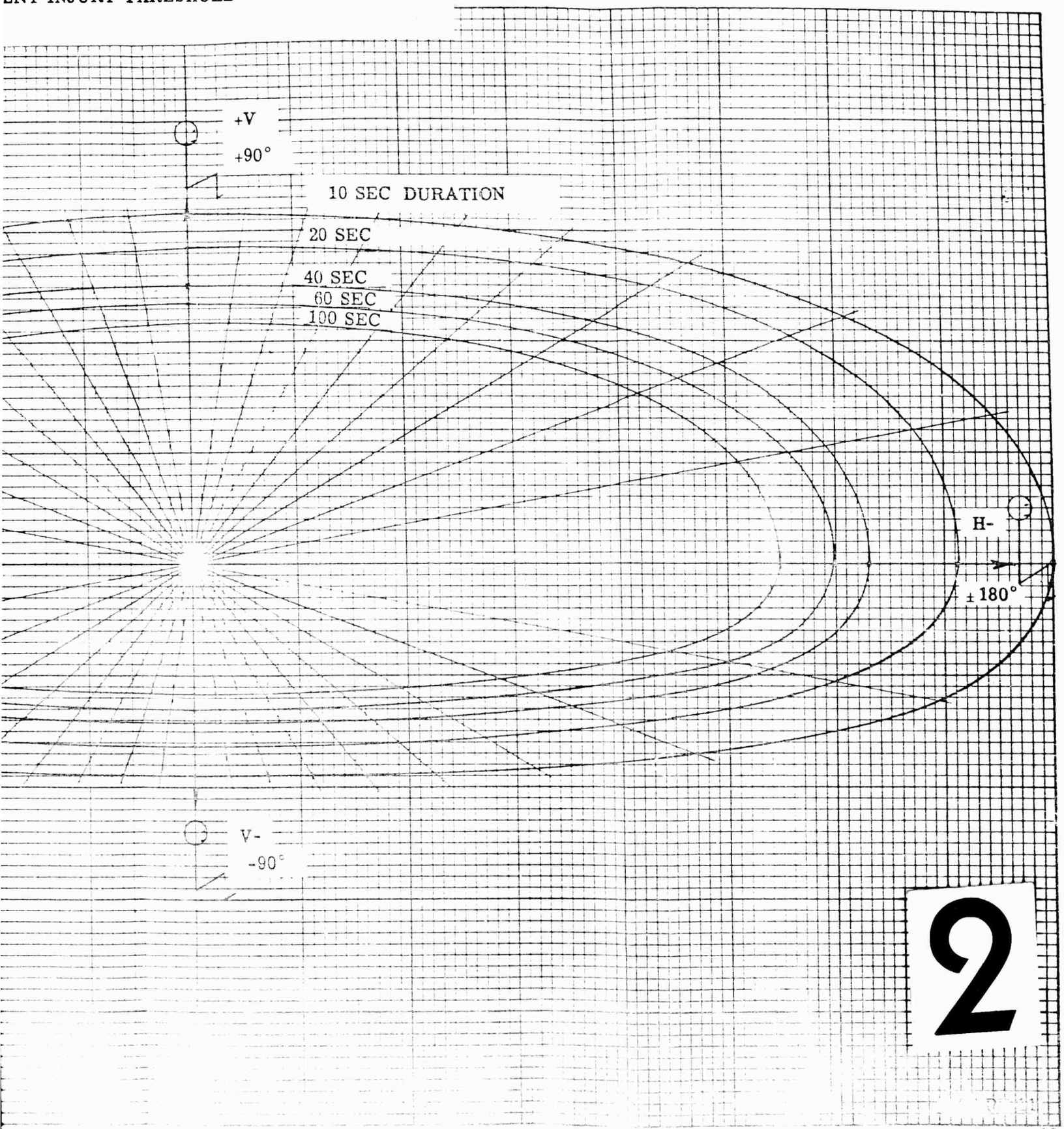
NOTES:

1. SCALE 1" = 6 "G"

2. "G" MEASURED RADIALLY

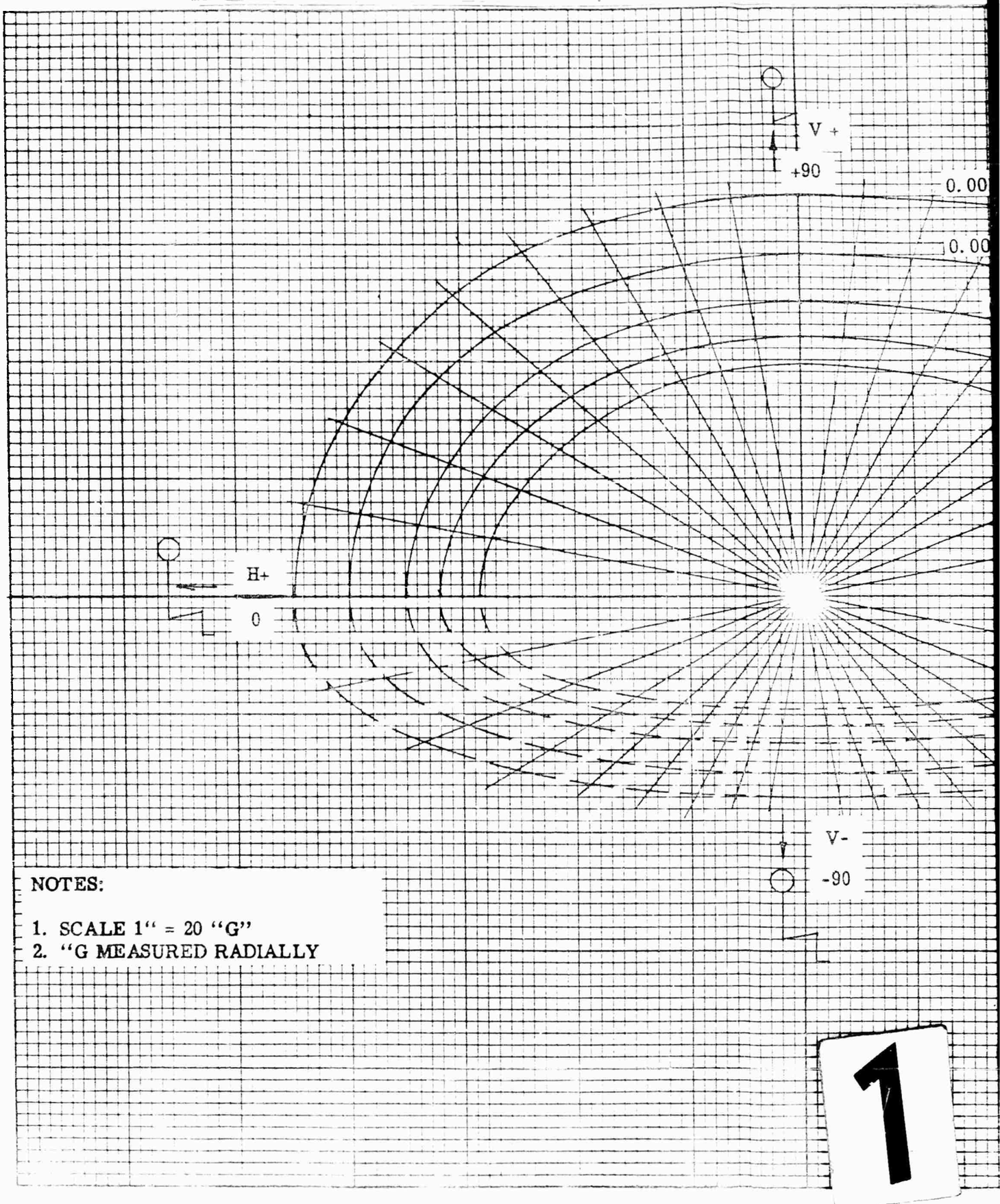
1

ENT INJURY THRESHOLD - DURATION 10-100 SECONDS



2

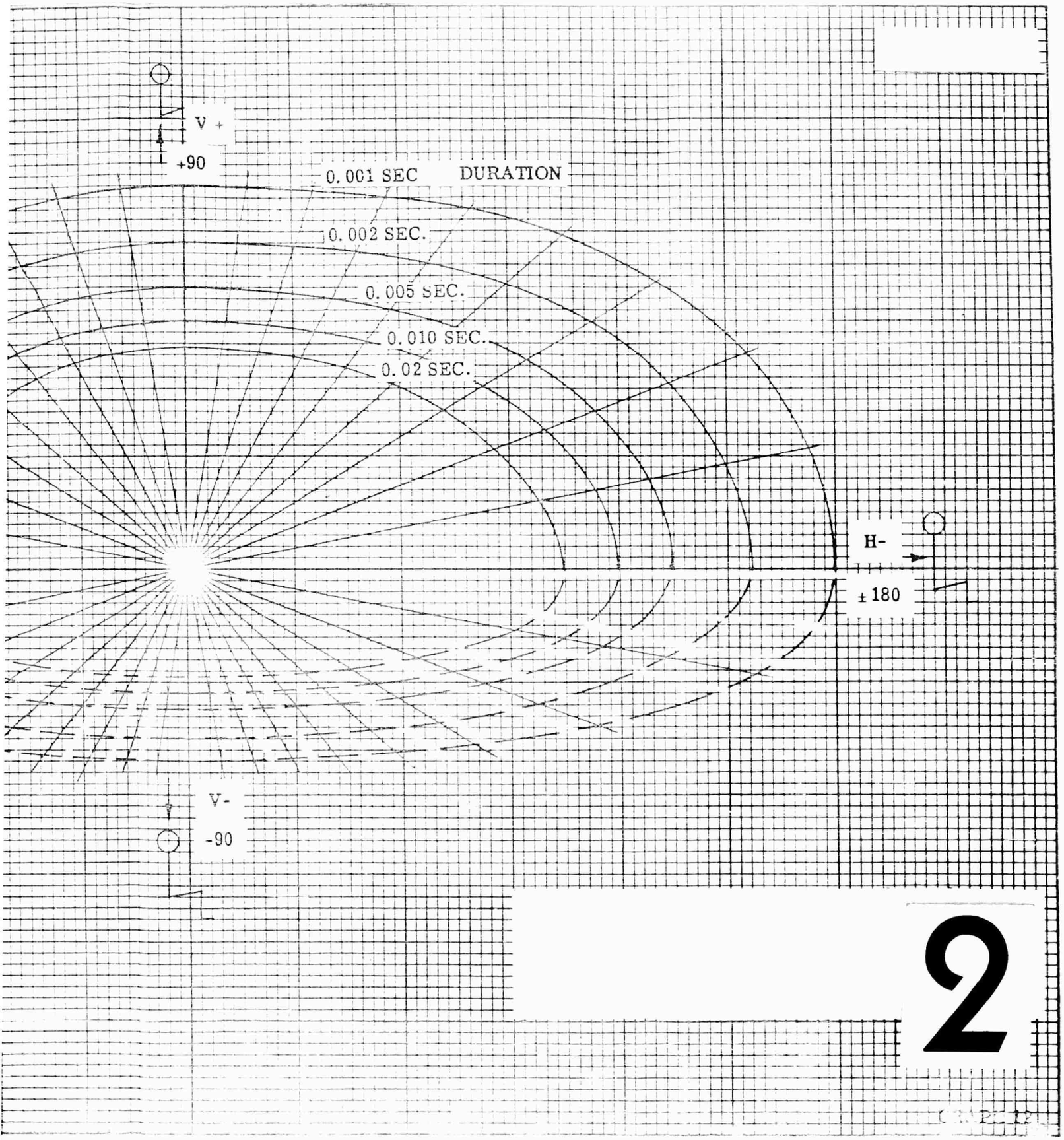
VOLUNTARY TOLERANCE TO ACCELERATIONS - DURATIONS 0.001 - 0.02 SEC



NOTES:

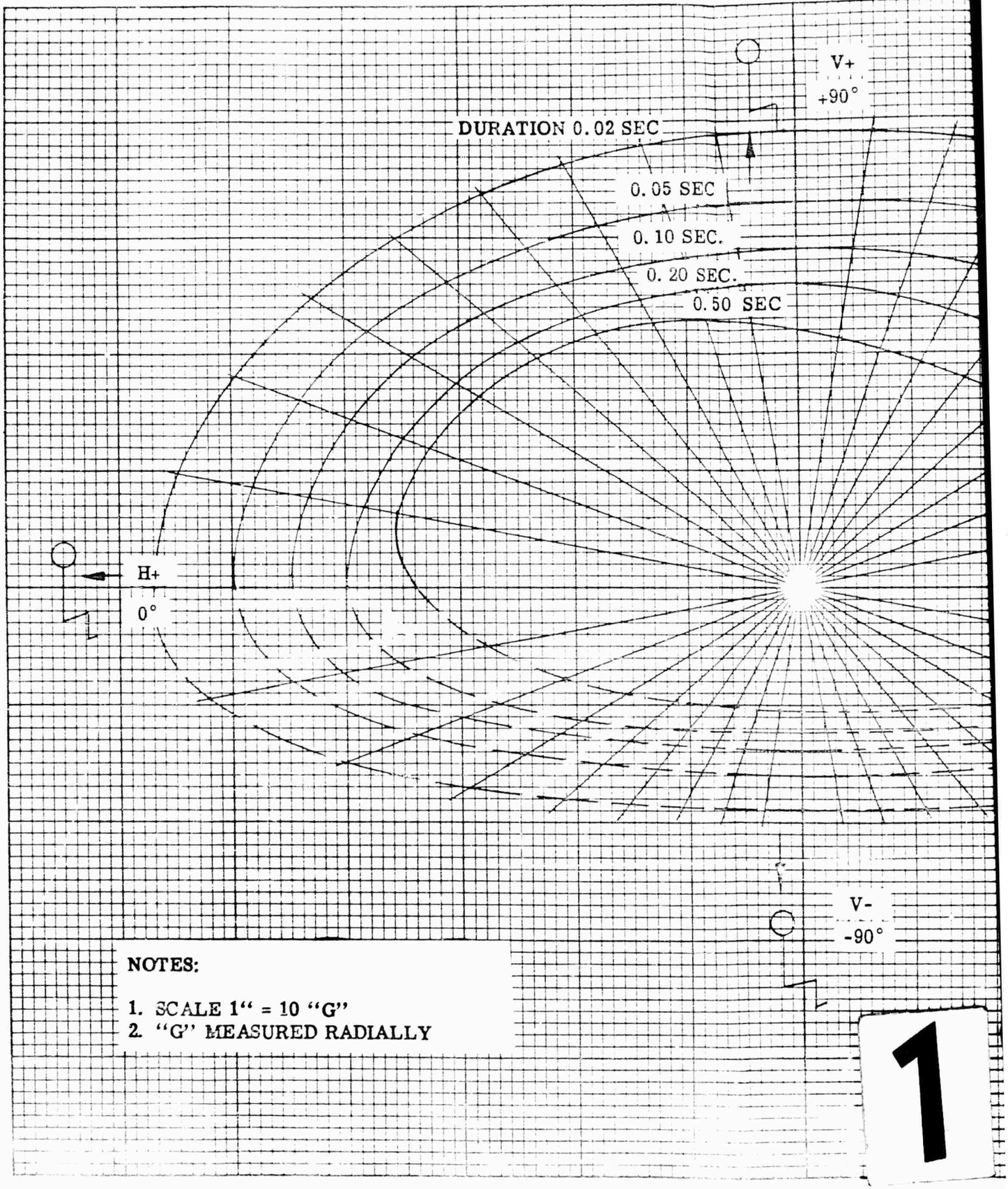
1. SCALE 1" = 20 "G"
2. "G MEASURED RADIALLY

1


V +
+90
0.001 SEC DURATION
0.002 SEC.
0.005 SEC.
0.010 SEC.
0.02 SEC.
H-
±180
V-
-90

2

VOLUNTARY TOLERANCE TO ACCELERATION

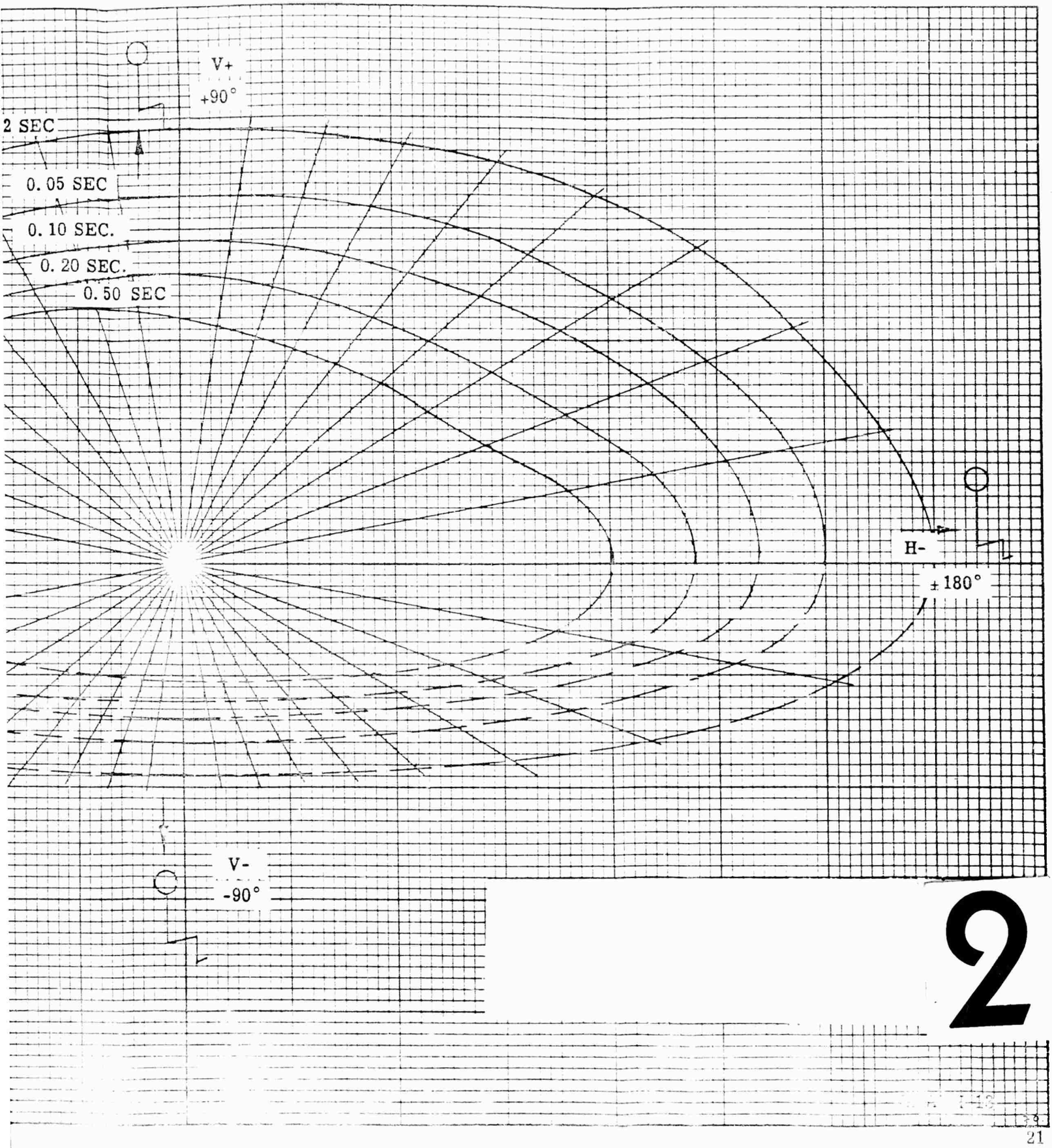


NOTES:

1. SCALE 1" = 10 "G"
2. "G" MEASURED RADIALLY

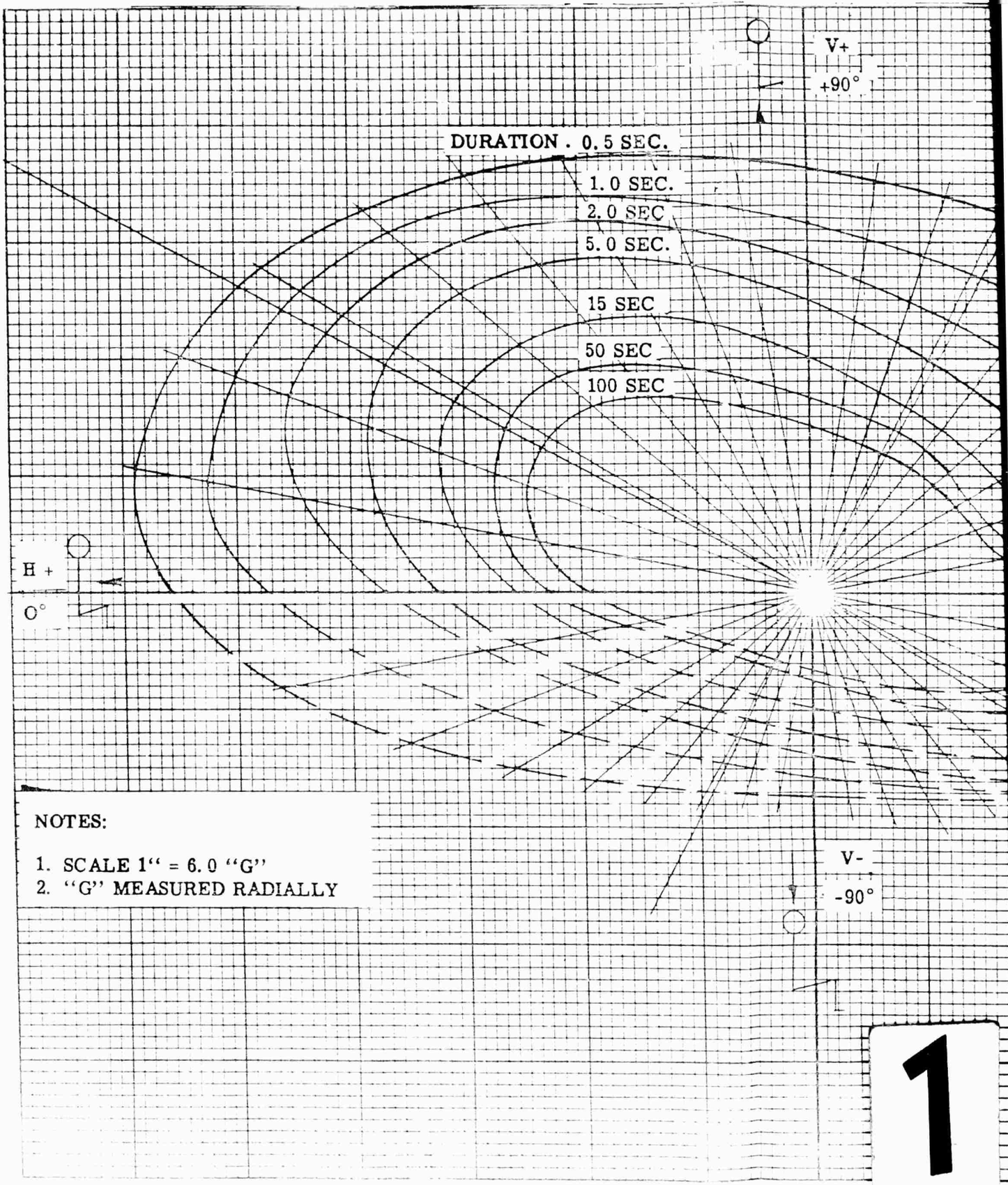
1

Y TOLERANCE TO ACCELERATION - DURATION 0.02 - 0.50 SECOND



2

VOLUNTARY TOLERANCE TO ACCELERATIONS - DURATION

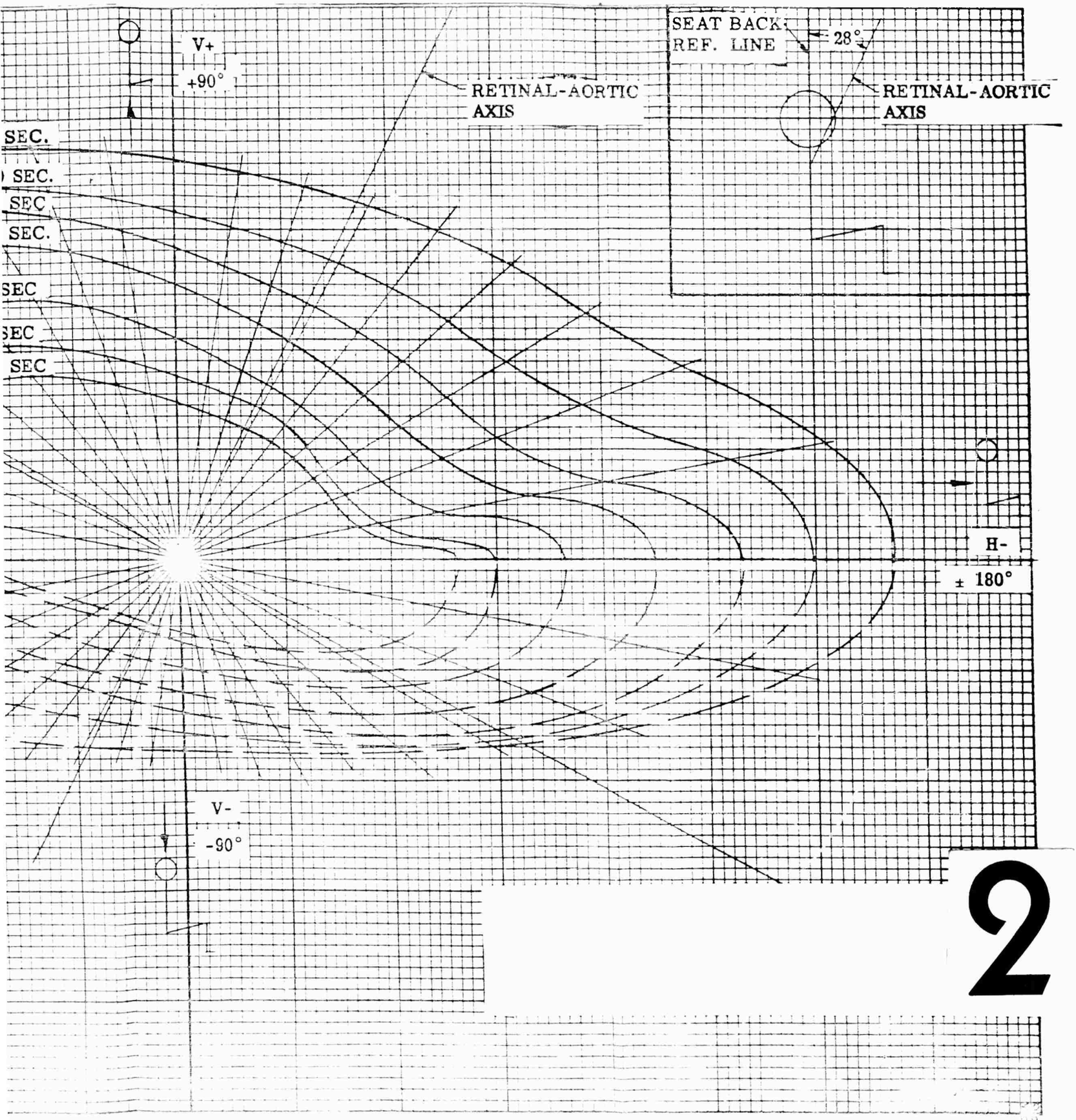


NOTES:

1. SCALE 1" = 6.0 "G"
2. "G" MEASURED RADIALLY

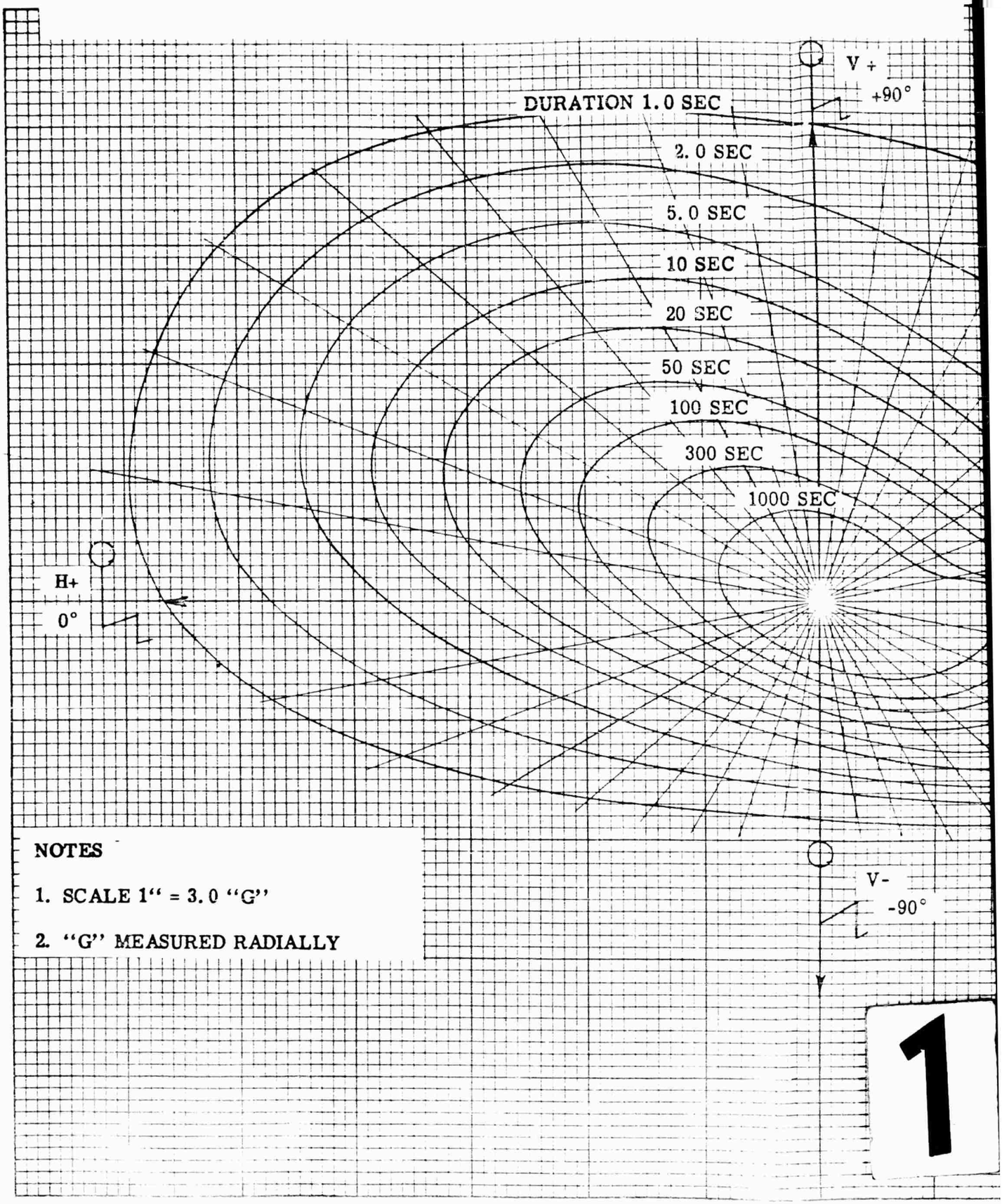
1

CE TO ACCELERATIONS - DURATIONS 0.5 - 100 SECONDS



2

LIMITS OF USEFUL CONSCIOUSNESS DURATION 1.

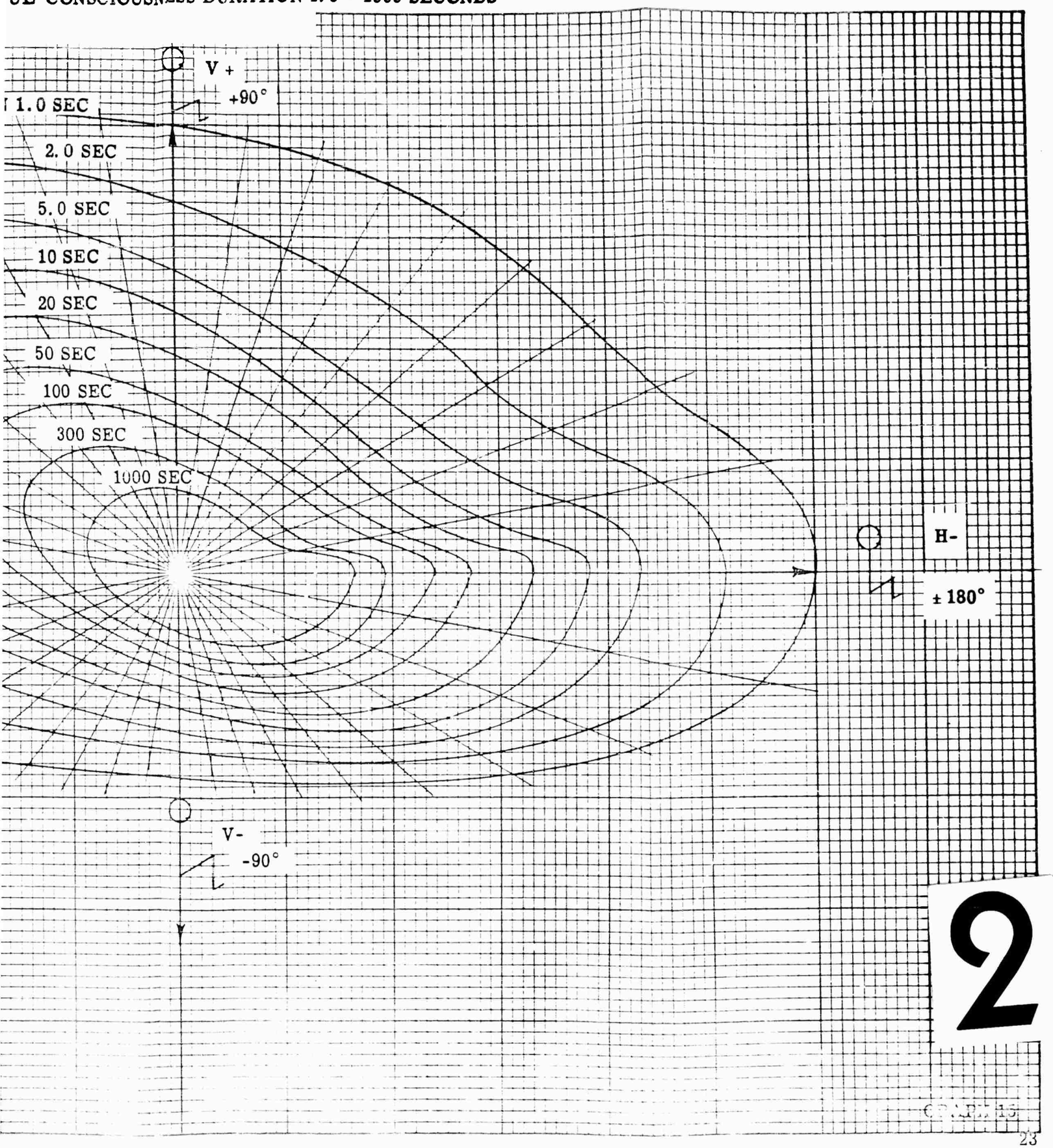


NOTES

1. SCALE 1" = 3.0 "G"
2. "G" MEASURED RADIALLY

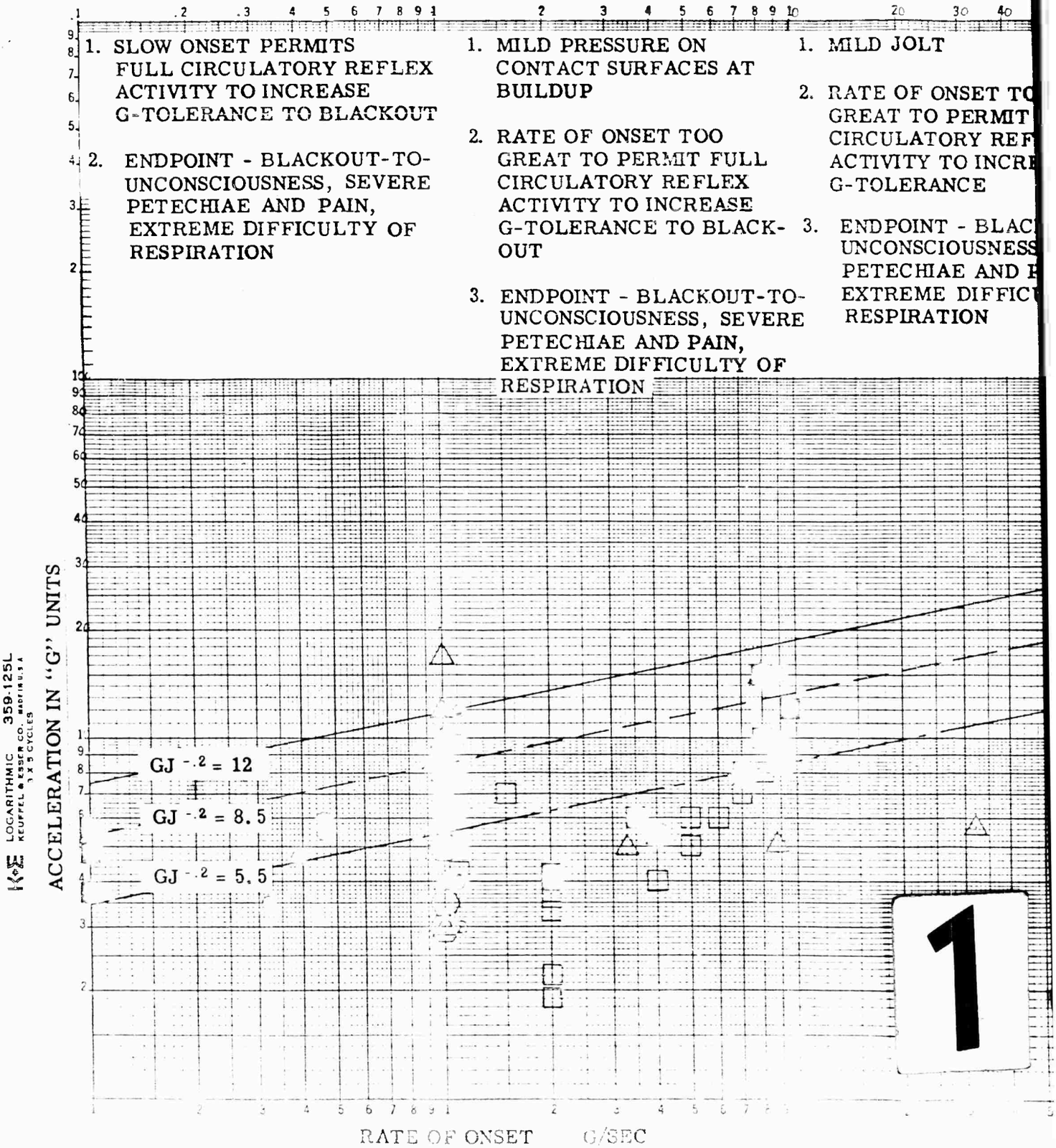
1

'UL CONSCIOUSNESS DURATION 1.0 - 1000 SECONDS

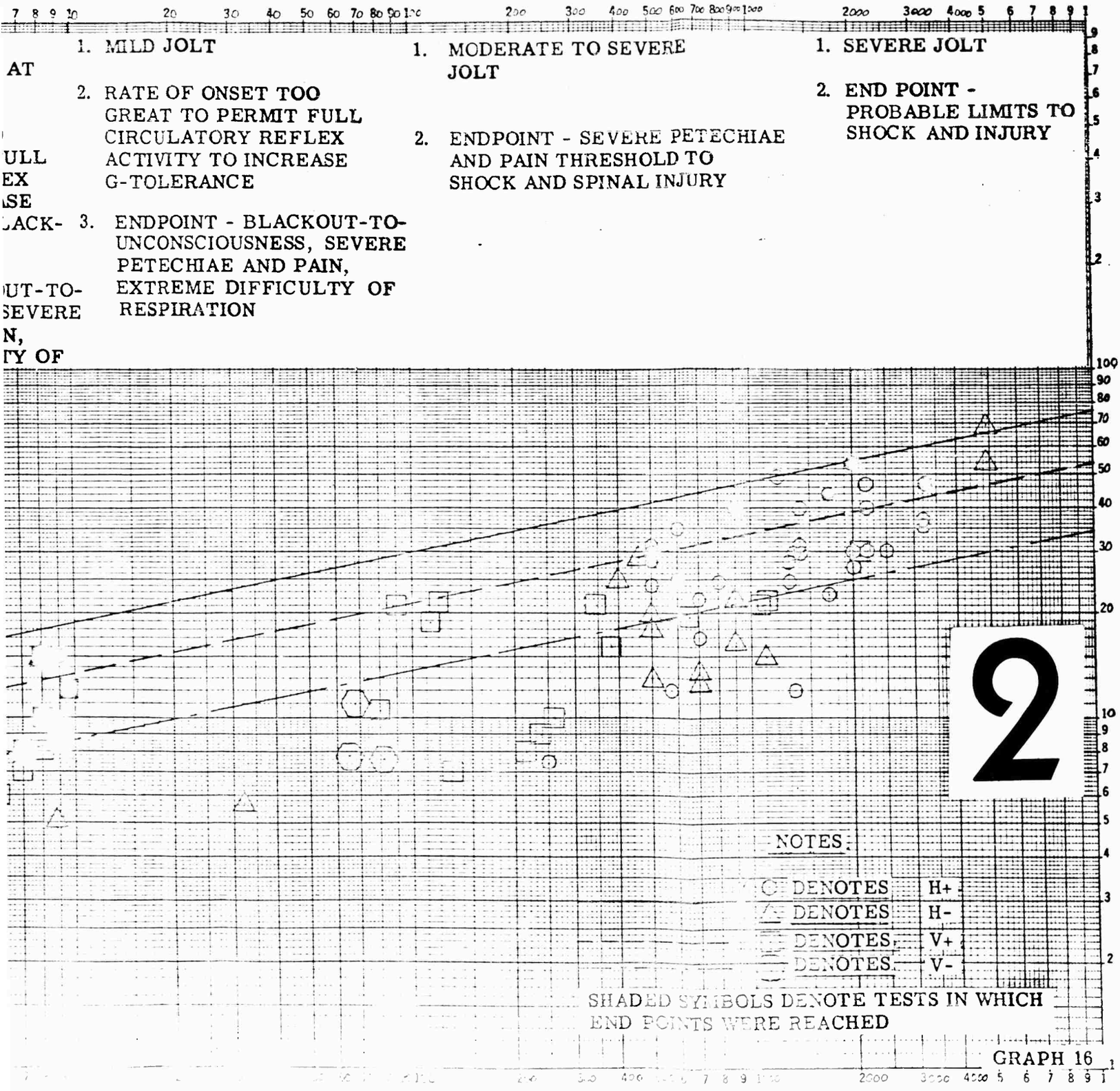


2

VOLUNTARY TOLERANCE TO ACCELERATION - RATE OF ON



CCELERATION - RATE OF ONSET STUDY

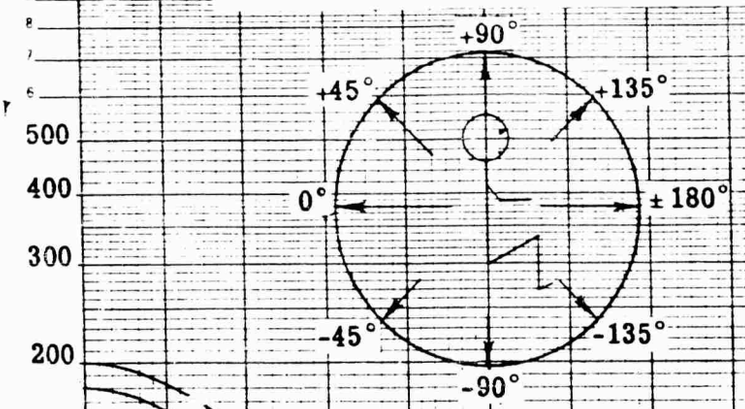


GRAPH 16

HUMAN TOLERANCE TO ACCELERA

REFERENCE CHART INDICATING PERMANENT IN

NOTE: MAXI
MAY
ON G
TO 1



EXTERNAL FORCE DIRECTION

ACCELERATION IN "G" UNITS

10 9 8 7 6 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1

.001 .002 .004 .006 .01 .02 .04 .10 .20 .40 1.0 2.0 4.0 10 20 40 60 100

HEMORRHAGE, SHOCK, INJURY.

HEMORRHAGE, ANOXIA SPINAL INJURY

HEMORRHAGE, SHOCK, INJURY

-180° -168° -156° -144° -132° -120° -108° -96° -84° -72° -60° -48° -36° -24° -12° 0° 12°

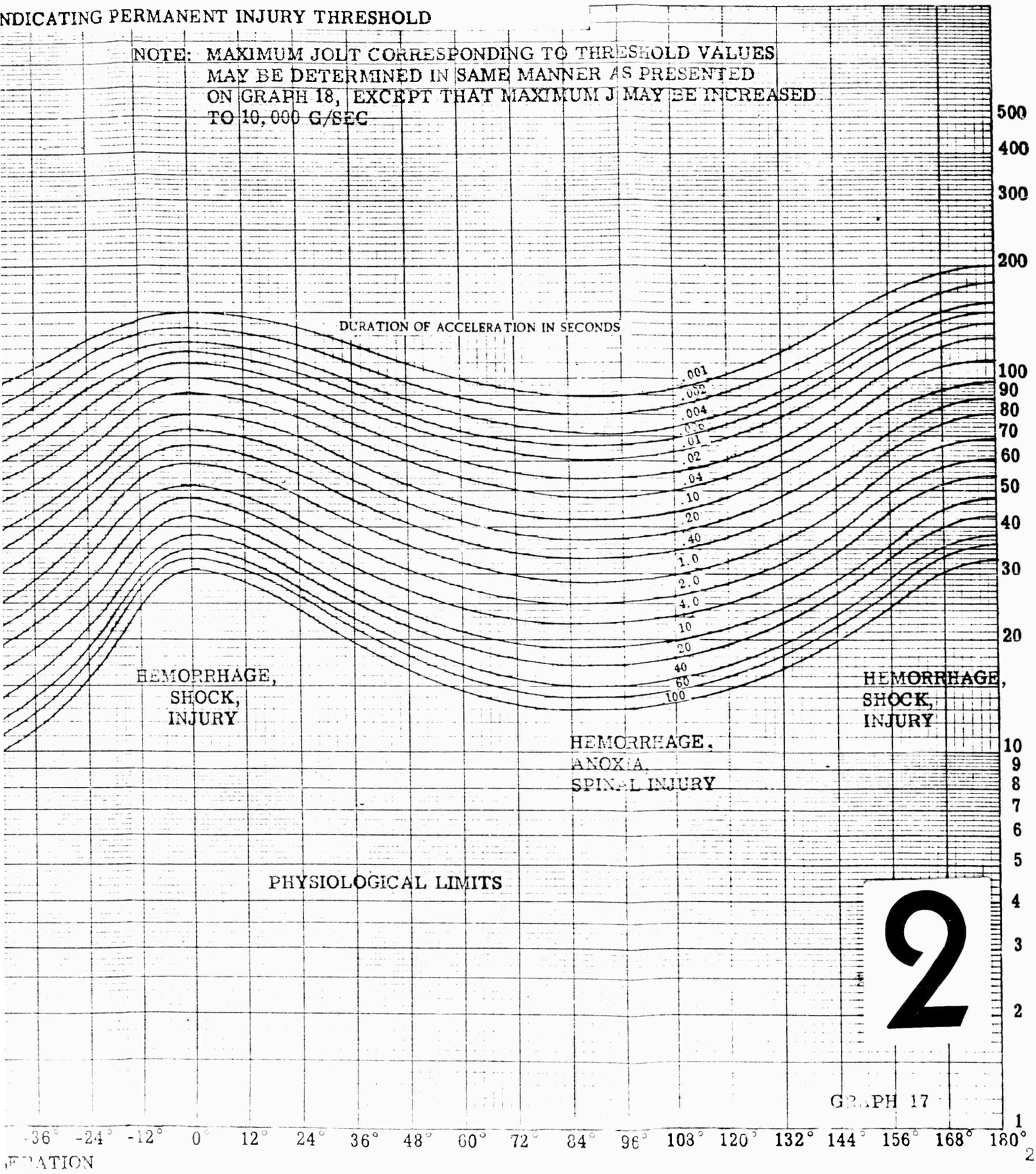
DIRECTION OF ACCELERATION

1

TOLERANCE TO ACCELERATION

INDICATING PERMANENT INJURY THRESHOLD

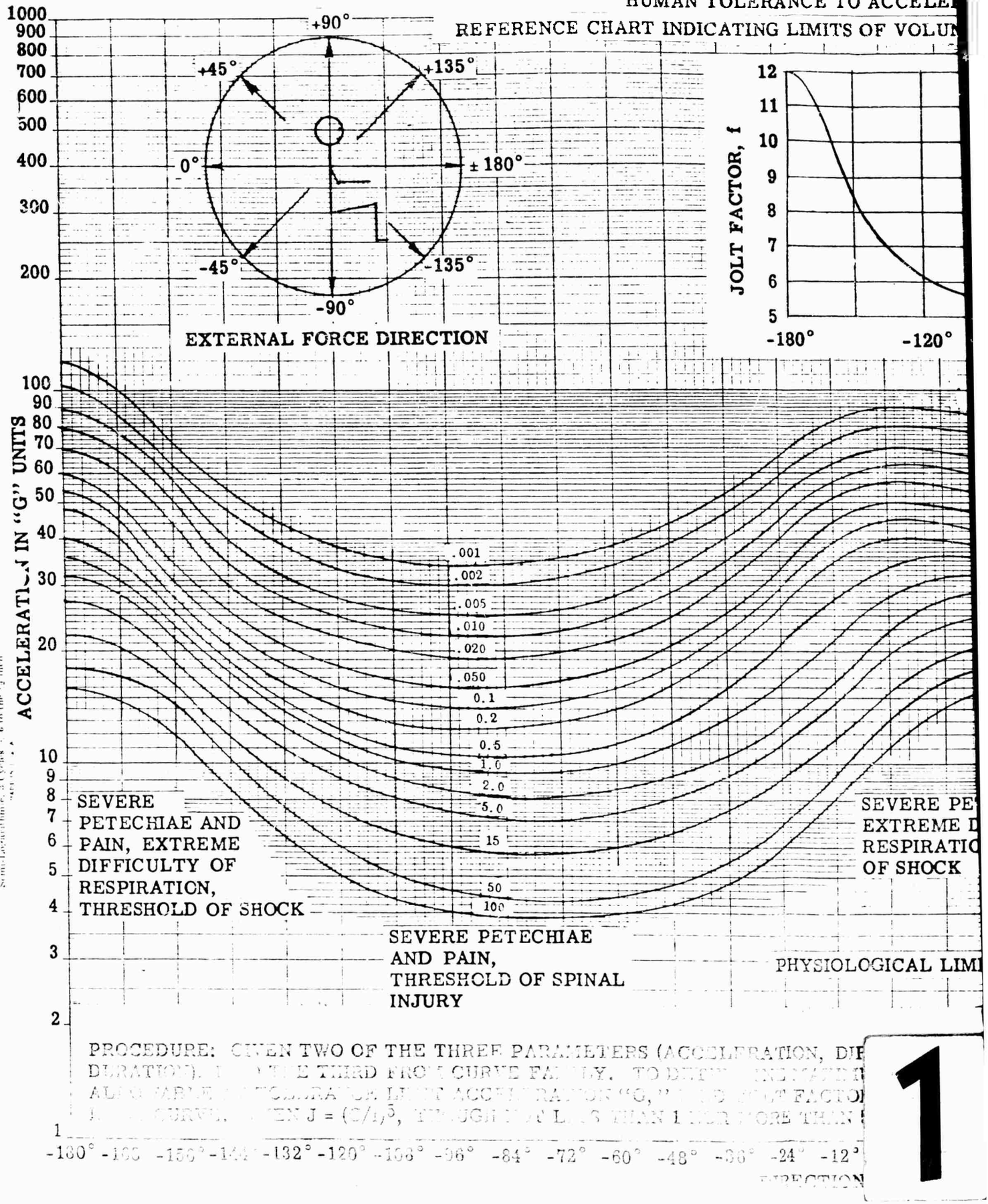
NOTE: MAXIMUM JOLT CORRESPONDING TO THRESHOLD VALUES MAY BE DETERMINED IN SAME MANNER AS PRESENTED ON GRAPH 18, EXCEPT THAT MAXIMUM J MAY BE INCREASED TO 10,000 G/SEC



2

GRAPH 17

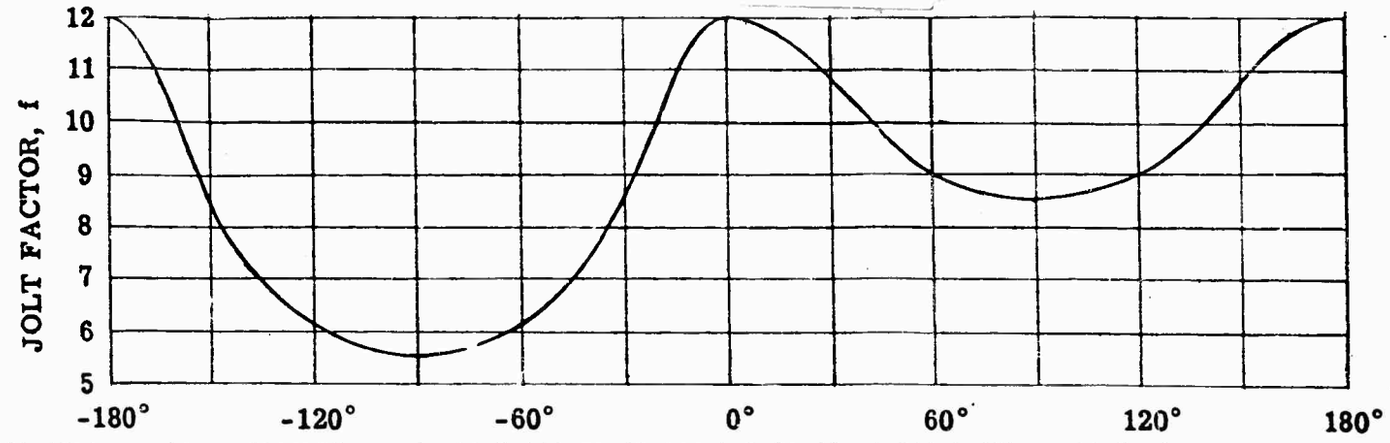
ERATION


HUMAN TOLERANCE TO ACCELE
REFERENCE CHART INDICATING LIMITS OF VOLU
+90°
+45°
+135°
0°
± 180°
-45°
-135°
-90°
EXTERNAL FORCE DIRECTION
JOLT FACTOR, f
12
11
10
9
8
7
6
5
-180°
-120°
ACCELERATION IN "G" UNITS
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
.001
.002
.005
.010
.020
.050
0.1
0.2
0.5
1.0
2.0
5.0
15
50
100
SEVERE PETECHIAE AND PAIN, EXTREME DIFFICULTY OF RESPIRATION, THRESHOLD OF SHOCK
SEVERE PE
EXTREME D
RESPIRATIO
OF SHOCK
SEVERE PETECHIAE AND PAIN, THRESHOLD OF SPINAL INJURY
PHYSIOLOGICAL LIMI
PROCEDURE: GIVEN TWO OF THE THREE PARAMETERS (ACCELERATION, DI
DURATION), E
THE THIRD FRO
CURVE FA
LY. TO DETE
IN
AL
ARLE
TOLERANCE LIMIT ACCELERATION "G," AND JOLT FACTO
CURVE. WHEN J = (G/t)^5, THOUGH
IS LESS THAN 1 OR MORE THAN
-180° -168° -156° -144° -132° -120° -108° -96° -84° -72° -60° -48° -36° -24° -12°
DIRECTION
1

2

UMAN TOLERANCE TO ACCELERATION

T INDICATING LIMITS OF VOLUNTARY TOLERANCE



DURATION OF ACCELERATION IN SECONDS

.001
.002
.005
.010
.020
.050
0.1
0.2
0.5
1.0
2.0
5.0
15
50
100

1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1

SEVERE PETECHIAE AND PAIN, EXTREME DIFFICULTY OF RESPIRATION, THRESHOLD OF SHOCK

BLACKOUT-TO-UNCONSCIOUSNESS, SEVERE PETECHIAE, THRESHOLD OF SPINAL INJURY

SEVERE PETECHIAE AND PAIN, EXTREME DIFFICULTY OF RESPIRATION, THRESHOLD OF SHOCK

PHYSIOLOGICAL LIMITS

G = ACCELERATION MAGNITUDE

J = JOLT, OR RATE OF ONSET OF G

f = JOLT FACTOR, FROM INSET CURVE

$J = (G/f)^5$ BUT ≥ 1 & ≤ 5000

(ACCELERATION, DIRECTION,
[illegible] JOLT "J"
[illegible] JOLT FACTOR "f" ON
[illegible] MORE THAN 5000 G/SEC

GRAPH 18

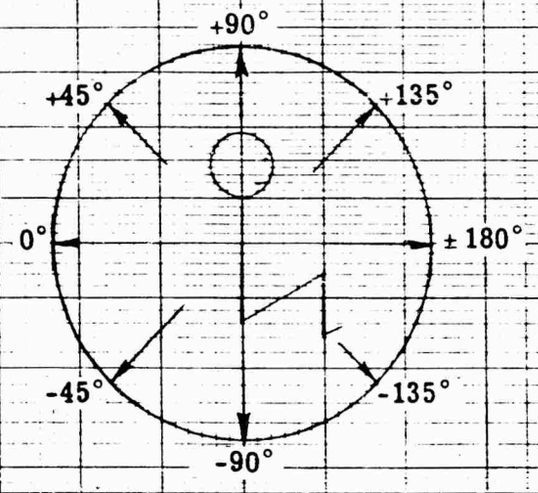
-48° -36° -24° -12° 0° 12° 24° 36° [illegible] 72° 84° 96° 108° 120° 132° 144° 156° 168° 180°

DIRECTION OF ACCELERATION

HUMAN TOLERANCE TO ACCELERATION

REFERENCE CHART INDICATING LIMITS OF USEFUL CON

NOTE: RATE
BETV
SIGN



EXTERNAL FORCE DIRECTION

1

ACCELERATION IN "G" UNITS

1.0
2.0
5.0
10
20
50
100
1000

PETECHIAE
PAIN,
DIFFICULTY OF
RESPIRATION

PETECHIAE, PAIN,
DIFFICULTY OF RES

PAIN,
PETECHIAE

PHYSIOLO

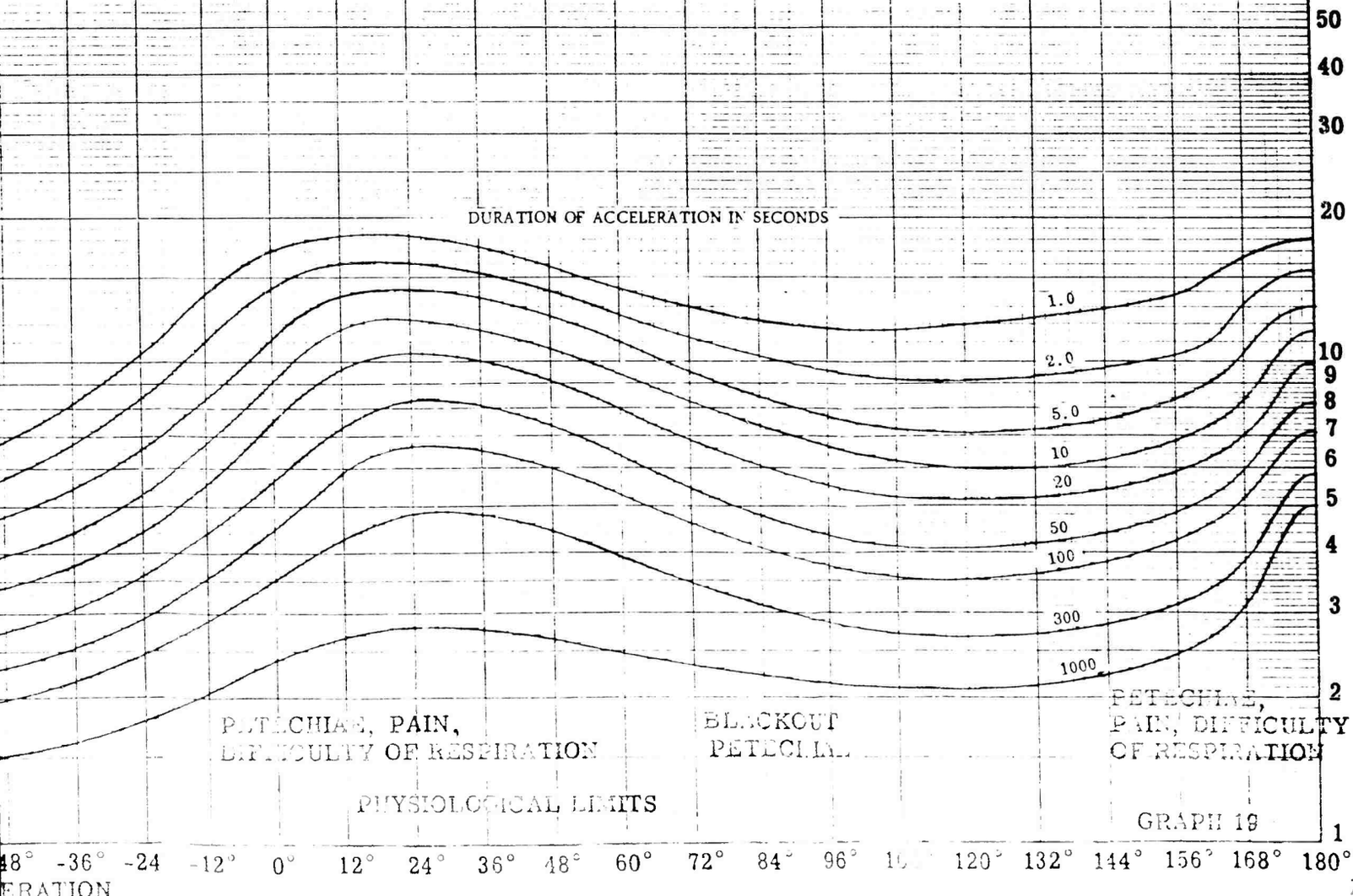
-180° -168° -156° -144° -132° -120° -108° -96° -84° -72° -60° -48° -36° -24 -12° 0° 12° 24°

DIRECTION OF ACCELERATION

TOLERANCE TO ACCELERATION
INDICATING LIMITS OF USEFUL CONSCIOUSNESS

NOTE: RATE OF ONSET OF ACCELERATION OR "JOLT" IS ASSUMED TO BE BETWEEN 1 G/SECOND TO 100 G/SECOND, AS MEASURED ON THE SIGNIFICANT SLOPE OF THE ACCELERATION-TIME CURVE

2



REFERENCES

1. Ballinger, E. R., and Dempsey, C. A.: The Effect of Prolonged Acceleration on the Human Body in the Prone and Supine Position. USAF Aero Med. Lab. Rpt. No. WADC 52-250, July 1952.

2. Beckman, E. L.; Ziegler, J. E.; Duane, T. D., and Hunter, H. H.: Preliminary Studies in Primates Subjected to Maximum Simple Accelerative Loads. USN Av. Med. Accel. Lab., Rpt. No. NADC-MA-5301, May 1953.

3. Beckman, E. L.; Duane, T. D.; Ziegler, J. E., and Hunter, H. N.: Human Tolerance to High Positive G Applied at a Rate of 5 to 10 G Per Second. USN Av. Med. Accel. Lab., Rpt. No. NADC-MA-5302, June 1953

4. Castor, J. G. B.: Acceleration (G-Forces) Research Equipment Studies, Results and Training. Hq. Air Materiel Command, Air Technical Intelligence Review, Rpt. No. F-IR-127-RE, December 1946.

5. DeHaven, H.: Mechanical Analysis of Survival in Falls from Heights of Fifty to One Hundred and Fifty Feet. War Medicine., 2:586, 1942.

6. Duane, T. D.: Preliminary Investigation Into the Study of the Fundus Oculi of Human Subjects under Positive Acceleration. USN Av. Med. Accel. Lab., Rpt. No. NADC-MA-5303, July 1953

7. Duane, T. D.; Beckman, E. L.; Ziegler, J. E., and Hunter, H. N.: Some Observations on Human Tolerance to Exposures of 15 Transverse G. USN Av. Med. Accel. Lab. Rpt. No. NADC-MA-5305, July 1953.

8. Duane, T. D.; Beckman, E. L.; Ziegler, J. E., and Hunter, H. N.: Some Observations on Human Tolerance to Accelerative Stress, III. Human Studies of Fifteen Transverse G. J. Av. Med., 26:298, 1955

9. Edelberg, R.; Henry, J. P.; Maciolek, J. A.; Salzman, E. W., and Zuidema, G. D.: Comparison of Human Tolerance to Accelerations of Slow and Rapid Onset. J. Av. Med., 27:482, 1956.

10. Gamble, V. L., and Shaw, R. S.: Animal Studies of Impact Negative Acceleration. Air Materiel Command Memo Rpt. No. MCREXD-695-74G, 1948.

11. Gell, C. F., and Cranmore, D.: Dislocation of Organs and Tissues of Rats Exposed to Acceleration Stress. J. Av. Med., 27:497, 1956.

12. Gell, C. F., and Hunter, H. N.: Physiological Investigation of Increasing Resistance to Blackout by Progressive Backward Tilting to the Supine Position. J. Av. Med., 25:568, 1954.

13. Hegenwald, J. F., Jr.: Human Tolerance to Accelerations. North American Aviation, Inc., Rept. No. NA-54-191, February 1954.

14. Hegenwald, J. F., Jr.: High Performance Ejection Seat. Phase I Preliminary Investigation. Contract AF33(616)-3327. North American Aviation, Inc., Rept. No. NA-56-377, September 1956.

15. Hegenwald, J. F., Jr., and Blockley, W. V.: Survivable Supersonic Ejection - A Case Study to Correlate Analytical, Experimental, and Medical Data by Reconstruction of an Incident. North American Aviation, Inc., Rpt. No. NA-56-452, April 1956.

16. Henry, J. P.: Studies of the Physiology of Negative Acceleration. Air Materiel Command Tech. Rpt. No. 5953, October 1950.

17. Lewis, D. H.: An Analysis of Some Current Methods of G-Protection. J. Av. Med. 26:479, 1955.

18. Lombard, C. F.: How Much Force Can the Body Withstand? Aviation Week 51:20-23, 1949.

19. Lovelace, W. R.; Baldes, E. J., and Wulff, V. J.: The Ejection Seat for Emergency Escape From High-speed Aircraft, AAF Air Technical Service Command Memo Rpt. No. TSEAL-3-696-74C, August 1945.

20. Lund, D. W.: Effect of Positional Variation on Man's Tolerance to "G". Air Materiel Command Memo Rpt. No. TSEAA-695-72B, June 1947.

21. Maciolek, J. A.: Circulatory Reflex Activity as G-Protective Device. USAF Aero Med. Lab. Tech. Note No. WCRD-55-1, January 1955.

22. Martin, E. E., and Henry, J. P.: The Supine Position As a Means of Increasing Tolerance to Acceleration. Air Materiel Command, AF Tech. Rpt. No. 6025, August 1950.

23. Miller, C. O.: Evaluation of Transverse Acceleration (Rear to Front) Utilizing Conventional and Special Restraint Gear. Chance Vought Aircraft, Inc. Rept. No. 10816, February 1957.

24. Shaw, R. S.: Human Tolerance to Negative G of Short Duration. Air Materiel Command, AF Memo Rept. No. TSEAA-695-74, May 1947.

25. Shaw, R. S.: Human Tolerance to Acceleration in Downward Seat Ejection. Air Materiel Command, AF Memo Rpt. No. TSEAA-695-74C, December 1947.

26. Stapp, J. P.: Human Exposures to Linear Deceleration. Part II. The Forward-Facing Position and the Development of a Crash Harness. Aero Med. Lab. AF Tech. Rpt. No. 5915, December 1951.

27. Stapp, J. P.: Human Exposures to Linear Deceleration. Part I. Preliminary Survey of the Aft-Facing Seated Position. Aero Med. Lab. AF Tech. Rpt. No. 5915, June 1949.

28. Stapp, J. P.: Human and Chimpanzee Tolerance to Linear Decelerative Force. Paper presented at conference on Problems of Emergency Escape in High-speed Flight, September 1952.

29. Stapp, J. P.: Effects of Mechanical Force on Living Tissues. J. Av. Med., 26:268, 1955.

30. Stauffer, F. R.: Studies on the Effectiveness of Automatic Supination in Protecting Man Against High Radial Acceleration. USN Sch. of Av. Med., Rpt. No. NM 001 059.02.07, 1951.

31. Stoll, A. M.: Human Tolerance to Positive G as Determined by the Physiological End Points. J. Av. Med., 27:356, 1956.

32. Watts, D. T.; Mendelson, E. S., and Kornfield, A. T.: Human Tolerance to Accelerations Applied From Seat to Head During Ejection Seat Tests. USN Bureau of Aeronautics, Aero Med. Equip. Lab. Rpt. No. TED-NAM-256005, January 1947.

33. Webster, A. P., and Hunter, H. N.: Acceleration Chart, J. Av. Med. 25:378-379, 1954.

34. Winquist, P. G.; Stumm, P. W., and Hansen, R.: Crash Injury Experiments With the Monorail Decelerator. USAF Air Res. and Dev. Command, Tech. Rpt. No. AFFTC 53-7, 1953.